HW)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: June 4, 1979

Project Title: Nuclear and X-Ray Spectroscopy with Radioactive Sources

Project No: G-33-645 Green card

Project Director: Dr. R. W. Fink

Sponsor: Department of Energy; Oak Ridge Operations; Oak Ridge, TN 37830

Agreement Period: From 2/1/79 Until 1/31/80 (Mod. M015 Period)

Type Agreement: Contract No. DE-AS05-76ER03346, Mod. No. M015 (formerly contract no. EY-76-S-05-3346)

Amount: $85,000 New DOE Funds (G-33-645)
14,634 DOE Funds From Prior Period(s)
44,862 GIT Contribution G-33-338)
$144,496 Total Est. Cost

Reports Required: Publication Preprints; Publication Reprints; Annual Progress Reports; Final Report

Sponsor Contact Person (s):

Technical Matters

Contractual Matters
(thru OCA)

Mr. A. H. Frost, Jr., Chief
Contract Management Branch
Procurement and Contracts Division
U. S. Department of Energy
Oak Ridge Operations
P. O. Box E
Oak Ridge, TN 37830

Mr. Walker Love
615/576-0791

NOTE: FOLLOW-ON PROJECT TO G-33-632 (Mod. No. A014)

Defense Priority Rating: None

Assigned to: Chemistry (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
- Dean/Director—EES
- Accounting Office
- Procurement Office
- Security Coordinator (OCA)
- Reports Coordinator (OCA)
- Library, Technical Reports Section
- EES Information Office
- EES Reports & Procedures
- Project File (OCA)
- Project Code (GTRI)
- Other ______

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 1/29/81

Project Title: Nuclear and X-Ray Spectroscopy with Radioactive Sources

Project No: G-33-645

Project Director: Dr. R. W. Fink

Sponsor: Department of Energy; Oak Ridge Operations; Oak Ridge, TN 37830

Effective Termination Date: 1/31/80 (Mod. M015 Period)

Clearance of Accounting Charges: 1/31/80

Grant/Contract Closeout Actions Remaining:

- _ Final Invoice and Closing Documents
- X Final Fiscal Report (Cert. Statement of Costs)
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________

NOTE: Follow-On Project to be G-33-659

Assigned to: Chemistry (School/~~Laboratory~~)

COPIES TO:

Project Director
Division Chief (EES)
School/Laboratory Director
Dean/Director—EES
Accounting Office
Procurement Office
Security Coordinator (OCA)
Reports Coordinator (OCA)
Library, Technical Reports Section
EES Information Office
Project File (OCA)
Project Code (GTRI)
Other C.E. Smith

CA-4 (1/79)

G-33-645

ORO–3346–236

NUCLEAR AND X–RAY SPECTROSCOPY WITH RADIOACTIVE SOURCES

Fifteenth Annual Progress Report
U. S. Department of Energy
Contract DE–AS05–76ERO–3346

R. W. Fink
Professor of Chemistry & Principal Investigator
and
John L. Wood
Research Scientist & Co–principal Investigator

October 31, 1979

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF CHEMISTRY
ATLANTA, GEORGIA 30332

Tel. (404) 894–4030

1979

NUCLEAR AND X-RAY SPECTROSCOPY WITH RADIOACTIVE SOURCES

Fifteenth Annual Progress Report

U. S. Department of Energy

Contract DE-AS05-76ERO-3346

R. W. Fink

Professor of Chemistry and Principal Investigator

and

J. L. Wood

Research Scientist and Co-principal Investigator

October 31, 1979

School of Chemistry

Georgia Institute of Technology

Atlanta, Georgia 30332

Telephone: (404) 894-4030

TABLE OF CONTENTS

FIGURES

1.0 Introduction and Brief Overview

The UNISOR part of our research program for this year has continued in regions adjacent to the Z = 82 closed shell. Our aim has been to determine the structural features of nuclei in this region in as complete a manner as as possible. This completeness is crucial to establishing systematic trends which underlie all of our interpretation of nuclear structure far from the beta-stable region.

This approach has been very successful in understanding the excited states of ^{187}Au populated in the decay of ^{187m,g}Hg. This decay scheme was the subject of the PhD thesis of M. A. Grimm and won a Georgia Tech Sigma Xi Research Prize ($200) for one of the best theses of the year.

Our continued testing of theories of particle—core coupling has now been extended to include the Interacting Boson—Fermion Approximation of F. Iachello. To this end, we have implemented the operation of the codes PHINT, ODDA, and associated routines on the CDC-Cyber-70 computer at Georgia Tech.

The visits of J. L. Wood to the Isotope Separator Group at GSI-Darmstadt, West Germany, have continued with a month spent there early in 1979 and has resulted in a joint UNISOR/GSI Separator Group study of the decay of ^{189}Pb, the UNISOR involvement also including Louisiana State University and University of Tennessee. Four invited papers on the UNISOR program were presented by J. L. Wood and are listed in Sect. 6.0 below.

Substantial improvements in accuracy have been achieved this year in determinations of L-subshell x-ray fluorescence yields and Coster-Kronig total transition probabilities, owing to a new experimental technique involving three-parameter XX•t coincidence measurements and to a new experimental method of determining the absolute correction for tailing in separating a partly-resolved doublet, such as the K_{α_1} and K_{α_2} x rays. The XX•t coincidence technique implemented on our ND-4420 multiparameter analyzer is similar to the $\gamma\gamma\cdot t$ coincidence method used at UNISOR with the Tennecomp and SEL computer-based analyzers. Such experimental work in our laboratory at Georgia Tech thus contributes not only to the important field of x-ray and radiation physics*, but also to the training of our graduate students in the techniques that they later will be using in UNISOR work.

---

*Our review article, "X-ray Fluorescence Yields, Auger, and Coster-Kronig Transition Probabilities,"W. Bambynek, B. Crasemann, R. W. Fink, H. U. Freund, Hans Mark, C. D. Swift, R. E. Price, and P. V. Rao, Revs. Modern Phys. 44, 716 - 813 (1972) turned out to be the third most cited physics paper in the years 1972 - 1975 according to E. Garfield, Current Contents (Institute for Scientific Information) 19, 5 (May 10, 1976), based on the Citation Index, and it is still the most cited reference in this field. A revision is planned for 1981. The only physics articles cited more often in 1972 - 1975 are two letters in the field of high energy physics.

2.0 NUCLEAR SPECTROSCOPY

2.1 Nuclear Systematics and Models

This year our program in nuclear systematics has been strongly directed at establishing criteria for the quality of the experimental data that ensure completeness in the observed excited states of nuclei. This is crucial to establishing systematic trends and places strong constraints on the interpretation of experimental data. The details are presented in refs. 1 and 2 in Sect. 6.0.

The explanation of the behavior of the $h_{9/2}$ intruder state in the odd-mass Tl, Au, and Ir isotopes is under continuing investigation in terms of a proton—neutron interaction and its relation to the interacting boson approximation (IBA).

With the advent[1] of an interacting boson—fermion approximation (IBFA) for the description of odd-nucleon coupling to the collective (boson) degrees

[1] F. Iachello and O. Scholten, to be published;
R. F. Casten and G. J. Smith, Phys. Rev. Lett. 43, 337 (1979)

of freedom of the IBA, we have commenced a comparison of the IBFA with other particle-core coupling models that we have been using (see Sect. 4.1 below).
(J. L. Wood)

2.2 Experimental Studies

2.2.1 Odd-Mass Hg Decays

The main features of the excited states of $^{185-193}$Au observed in our studies of the odd-mass Hg decays are incorporated in a paper[2] on the odd-mass Au isotopes that is in preparation in collaboration with E. F. Zganjar. The decay scheme of ^{193g}Hg will also be published separately in much greater detail. The extraordinarily complete ^{187m,g}Hg decay scheme (99 γ-lines between 100 and 700 keV!) continues to be elucidated. The major features found in common with other odd-mass Au isotopes appears in this paper[2]. Features unique to ^{187}Au are being pursued separately. Thus, we are preparing a short communication[3] on the observed particle—core

[2] "The Odd-Mass Au Isotopes: A Systematic Study," J. L. Wood, M. A. Grimm, and E. F. Zganjar (in preparation)

[3] "Band Mixing with E0 Transitions in ^{187}Au," M. A. Grimm, J. L. Wood, and E. F. Zganjar (in preparation)

$\pi h_{9/2} \otimes {}^{186}$Pt(0+,g.s.) and $\pi h_{9/2} \otimes {}^{186}$Pt(0+, 475 keV) and the E0 transitions connecting collective band members of these couplings. We are in the process of analyzing conversion electron data for the ^{187}Hg decays that are of a much high statistical quality than that available at the time of completion of Dr. Grimm's thesis (which was based on this decay scheme). These data are crucial to establishing the low-energy rotational states built upon the strongly deformed Nilsson states that we believe are populated in this decay.

2.2.2 Odd-Mass Tl Decays

The excited positive-parity states of $^{187-195}$Hg observed in our studies of the odd-mass Tl decays are discussed in a short communication[4] in preparation in collaboration with E. F. Zganjar. A discussion of the description of these positive-parity states in terms of the Meyer ter Vehn rigid triaxial rotor model with a varying Fermi energy is included. The decay scheme of ^{191m}Tl will be published separately in a paper[5] that is nearing completion. Work on the elucidation of the very complicated ^{193m,g}Tl decay scheme continues. The ^{195}Tl and ^{197}Tl decay schemes have been published (refs. 3 and 7 in Sect. 6.0). New data of greatly improved statistical quality on the decays of ^{187m,g}Tl are in the process of being analyzed. All of these decay schemes have undergone serious revision in the last year through the use of systematics. Most notably, we have succeeded in organizing the negative-parity states into simple band structures. This is discussed in ref. 2 of Sect. 6.0. A paper on the systematic features of the odd-mass Hg isotopes, based on these decay scheme studies, is presented.

2.2.3 Odd-Mass Pb Decays

The decay scheme of ^{193m}Pb, ^{195m}Pb, and ^{197m,g}Pb have been completed and appear in two papers (refs. 17 and 18 of Sect. 6.0) that are in the process of being submitted for publication. The halflives of the ^{197m,g}Pb isomers have been the subject of a short communication (ref. 4 in Sect. 6.0). This work has been conducted in collaboration with the University of Tennessee group, who have coordinated these studies. The

---

[4] "The Positive-Parity States in the $^{187-199}$Hg Isotopes," J. L. Wood, G. M. Gowdy, R. W. Fink, and E. F. Zganjar (in preparation)

[5] "The Decay of Mass Separated ^{191}Tl (5.42 m) to ^{191}Hg," G. M. Gowdy, J. L. Wood, and R. W. Fink (in preparation)

decay scheme of ^{189}Pb has been studied in collaboration with the group of E. Roeckl at GSI-Darmstadt and E. F. Zganjar (LSU) and L. L. Riedinger (Univ. of Tennessee). Gamma multispectrum scaling and $\gamma\gamma$ coincidence data were taken at Darmstadt and conversion electron data were taken at UNISOR. The data are in the process of being analyzed. The prime objective of this work is to determine if states due to the coupling $\pi h_{9/2} \otimes {}^{188}$Hg(0+,825 keV) and associated rotational modes occur in ^{189}Tl, or whether the occupancy of the $h_{9/2}$ orbital by the unpaired proton blocks this coupling due to a large contribution of the pair excitation $(\pi h_{9/2})^2_{J=0}$ to the strongly deformed 0+ state in ^{188}Hg at 825 keV. Work on the ^{191}Pb decay scheme is also in progress. This will provide a complete systematic on the excited states of the odd-mass Tl isotopes from ^{189}Tl to the beta-stability line.

(J. L. Wood)

2.2.4 Decay Scheme Studies in the A = 201 Mass Chain and the M4 Isomeric Transition in ^{201,199}Bi

The analysis of the decay scheme of ^{201m,g}Po (9 min, 14 min) and ^{201m,g}Bi (59 min, 1.8 h) isobars has continued. Mr. Paul Semmes, a senior chemistry undergraduate student, is working under the direction of Dr. R. A. Braga in the analysis of the γ-ray spectra taken at UNISOR.

The analysis of the band built upon the 1/2+ shell-model intruder state in Bi and of the 846 keV isomeric transition depopulating this state has been completed and submittal to Nuclear Physics A is planned*. The isomeric transition

*R. A. Braga, W. R. Western, J. L. Wood, R. W. Fink, R. Stone, C. R. Bingham, and L. L. Riedinger, "Very Slow M4 Transitions and Intruder States in ^{199,201}Bi," Nuclear Phys. A (to be published)

in ^{201m}Bi decay (59 min) is the only known "ℓ-forbidden" M4 transition in odd-A nuclei (the IT in ^{199m}Bi being unobserved) and is further expected to be hindered because it is a hole $\rightarrow$ particle transition.　(R. A. Braga)

2.2.5 Decay Scheme Studies in the A = 203 Mass Chain

Preliminary data on the decay of ^{203}At (7 min) have been obtained and are in the process of being analyzed. This work constitutes part of the doctoral thesis of Mr. Chris Papanicolopulos.

2.2.6 Odd-Mass Au Decays

The detailed study of the decays of $^{185,\ 187m,g,\ 189m,g}$Au to ^{185,187,189}Pt isotopes is in the planning stage. A new modified FEBIAD ion source, developed by R. L. Mlekodaj at UNISOR, shows excellent performance for ionization and extraction of gold isotopes. In particular it enabled us to obtain an approximate halflife for ^{187m}Au of ≈ 1 sec. This half-life has not been measurable before because the mass chain entry point previously has been confined to 2.2 min ^{187}Hg and ^{187}Tl. An earlier attempt to observe the isomer with the multiple-time analysis clock was confined to the half-life interval 100 μsec - 100 millisec. The decay scheme ^{187m,g}Au $\rightarrow$ ^{187}Pt will form part of the Ph.D. thesis of Mr. Bruce Gnade.

2.2.7 Nuclear Lifetime Measurements

Continuation of the measurement of lifetimes of levels in ^{109}Ag believed to be members of the $g_{7/2}$ intruder band by delayed coincidence techniques at Georgia Tech has been delayed due to the excessive time ($\approx$ 7 months) required for repair of our PGT Ge(Li) detector (see Sect. 4.2). With the return of this detector, we now plan to perform these measurements in 1979/80. (R. A. Braga)

2.3 International Comparison of Low-energy γ-ray Intensity Standard ^{133}Ba

The participation of our group in the international comparison of γ-ray emission-rate measurements on ^{133}Ba sources, supplied by the Laboratoire de Métrologie des Rayonnements Ionisants, Gif-sur-Yvette, France, and organized by the Working Group on Alpha-, Beta-, and Gamma-ray Spectroscopy of the

International Committee for Radionuclide Metrology (ICRM), chaired by J. Legrand (France), and adminstered in this country through the National Bureau of Standards, has been completed. The γ-rays measured for emission-rates are, in addition to the K x-rays, 53.155, 79.621, 80.997, 160.605, 223.25, 276.397, 302.851, 356.005, and 383.851 keV. Since large-volume Ge detectors exhibit a rapidly curving efficiency response in the region below 120 keV, we performed our measurements with small planar Si(Li) and Ge(HP) x-ray detectors, which exhibit linear efficiency curves (on log-log plots) in the region for Si(Li) above the 31 keV x rays, and for Ge(HP) above 120 keV. This results in much improved accuracy. Results from all participants will be summarized by J. Legrand, and we will report them in next year's annual progress report. (R. A. Braga, R. W. Fink, M. Tan, and B. E. Gnade)

2.4 Production of ^{18}F (110 min) in the Georgia Tech Reactor

There is strong interest in the Atlanta and Georgia area in ^{18}F -labelled organic compounds suitable as radiopharmaceuticals for positron emission transaxial tomography (PETT) in nuclear medicine. Previously, compounds such as 2-fluoro-2-deoxy-D-glucose have been prepared from gaseous fluorine-^{18}F produced at great cost in cyclotrons by the $^{20}Ne(d,\alpha)^{18}F$ or $^{18}O(p,n)^{18}F$ reactions with gaseous targets, and thus were unavailable in the Atlanta or Georgia area owing to lack of charged-particle accelerators. We are working on producing these compounds by utilizing the reaction sequence $^{6}Li(n,t)^{4}He$-$^{16}O(t,n)^{18}F$ in the Georgia Tech Research Reactor which produces copious yields (up to 250 millicuries of ^{18}F per hour per gram of 96% enriched ^{6}Li at a flux of 3.x 10^{13} n/cm$^{2}\cdot$sec). Following separation of carrier-free ^{18}F and removal of the $^{6}LiOH$ target material and tritium activity on stannic oxide columns, the radioactive ^{18}F will be introduced into the organic molecules using new organo-fluorine synthetic methods developed by Prof. Charles Liotta of the Georgia Tech School of Chemistry. With a reactor-based source of ^{18}F-labelled radiopharmaceuticals available in Atlanta, the Emory University Medical School Department of Nuclear Medicine will be able to proceed with the establishment of PETT scanning and acquire an ECAT scanning system. Our interest is to provide the nuclear chemistry/radiochemistry expertise needed in this collaborative effort as part of our broad-based program of nuclear chemistry at Georgia Tech. The biochemistry background and future interest in the field of nuclear medicine of Mr. Bruce Gnade also prompts this study, which is expected to convert to NIH funding in July, 1980, if it is to be continued as a long-term effort.

(R. W. Fink, B. E. Gnade, and C. L. Liotta)

3.0 X-RAYS FROM RADIOACTIVE SOURCES

3.1 L-Subshell X-ray Fluorescence and Coster-Kronig Transition Yields at Z = 64 and 67

This investigation of the $L_{2,3}$ subshell x-ray fluorescence yields and Coster-Kronig total transition probability at Z = 64 and 67 was carried out to provide a test of theory and improved values for experimental applications. Recently, some new relativistic calculations of radiationless transition rates to L-subshell vacancy states have been performed[1)] for selected elements with Z = 70 to 96. In this region, these calculated relativistic L-subshell widths agree with experimental values better than previous non-relativistic calculations[2,3,4)]. Relativistic calculations for lower-Z elements, however, are not yet available, but they are of interest in the light of the new experimental results reported here and our current effort to extend the measurements to Z = 54.

Accurate experimental values of L-subshell fluorescence and Coster-Kronig yields also are important in many practical applications, ranging from elemental analysis by x-ray emission techniques to basic studies of nuclear and atomic processes leading to emission of x rays and Auger electrons, such as electron capture, internal conversion, and ionization cross section measurements.

Previous measurements of the total L_2-L_3 Coster-Kronig transition probability f_{23} at Z = 65[5)] and 67[6,7)] reported higher values than those found in the present work, whereas the discrepancies between previous and present values of the L-subshell x-ray fluorescence yields ω_2 and ω_3 are small. In the present work much higher accuracy in the f_{23} measurements was achieved, based on significant improvements in the experimental technique and in data evaluation. These advances include (1) an improved electronics system and the use of much faster coincidence timing (made possible by using a three-parameter multichannel

XX·t coincidence configuration); (2) much better resolution and spectral quality of the K x rays through the use of a new, state-of-the-art ion-implanted Ge(HP) detector; (3) collimation to drastically reduce Compton backscattering from one detector to the other in the 180° coincidence geometry used; and (4) application of a new method[8] for the direct experimental determination of the absolute correction for tailing of K_{α_1} events into the K_{α_2} x-ray peak.

---

1) M. H. Chen, E. Laiman, B. Crasemann, M. Aoyagi, and Hans Mark, Phys. Rev. A 19 2053 (1979) and Bull. Am. Phys. Soc. 24, 624 (1979)
2) E. J. McGuire, Phys. Rev. A3, 587 (1971)
3) M. H. Chen, B. Crasemann, in Inner Shell Ionization Phenomena and Future Applications, by R. W. Fink, S. T. Manson, J. M. Palms, and P. V. Rao (U.S. Atomic Energy Commission, 1973); p. 43
4) M. H. Chen, B. Crasemann, and V. O. Kostroun, Phys. Rev. A4, 1 (1971)
5) D. G. Douglas, Can. J. Phys. 50, 1697 (1972)
6) C. P. Holmes, and V. O. Kostroun, Bull. Am. Phys. Soc. 15, 561 (1970)
7) D. G. Douglas, Can. J. Phys. 54, 1124 (1976)
8) B. E. Gnade, R. A. Braga, W. R. Western, J. L. Wood, and R. W. Fink, Nuclear Instr. Meth. 164, 163-167 (1979)

The total Coster-Kronig transition probability f_{23} for the L_2-L_3 transition and the L_2 and L_3 subshell x-ray fluorescence yields ω_2 and ω_3 were measured utilizing resolved L - K x-ray coincidence techniques for Z = 64 and 67 with radioactive sources of 4.68 y ^{155}Eu and 10.4 h ^{165}Er, respectively. Improved accuracy in the results is achieved by advances in the electronic system and coincidence timing, much improved resolution and spectral quality of an intrinsic Ge(HP) x-ray detector, collimation, and use of a new method of experimentally determining the absolute correction for tailing of K_{α_1} events into the K_{α_2} peak in the determination of f_{23}. Finding the magnitude of this correction experimentally is crucial, since values of f_{23} differ by as much as 15% from those obtained by using earlier methods on the present data. The values of f_{23} from the present work are 0.130 ± 0.012 and 0.115 ± 0.011 at $Z = 64$ and 67, respectively. The use of collimation drastically reduces Compton tailing in the resolved coincident L x-ray peaks and gives improved values of the L_2 and L_3 subshell x-ray fluorescence yields of $\omega_2 = 0.165 \pm 0.022$ and $\omega_3 = 0.161 \pm 0.019$ at $Z = 64$, and $\omega_2 = 0.186 \pm 0.023$ and $\omega_3 = 0.180 \pm 0.020$ at $Z = 67$, respectively. The quoted uncertainties are twice the average deviation from the mean of 12 values of f_{23} and two values each of ω_2 and ω_3, and arise predominantly from systematic errors. All previous determinations of f_{23} contain estimated systematic errors that are two to three times larger than those in the present work.

Previous measurements[5,6] of the L-subshell fluorescence yields ω_2 and ω_3 are in approximate agreement with the present results within the error limits. However, the previous values[5,7] of f_{23} lie significantly above the present ones and are outside experimental error limits. High values can result from the following experimental difficulties[5,7]: lack of sufficient energy resolution in the K and L x-ray detectors required to reduce the tailing correction to a minimum, use of a singles γ-ray line shape to estimate the tailing of K_{α_1} events in the K_{α_2} peak, apparent lack of correction for L_β tailing into the L_α peak, lack of sufficiently narrow prompt time gating in the two-parameter coincidence technique used[5,7], and lack of collimation to reduce the Compton continuum from backscattered events.

The non-relativistic theoretical calculation of McGuire[2] at Z = 67 predicts $\omega_2 = 0.203$, $\omega_3 = 0.201$, and $f_{23} = 0.138$, all of which lie considerably above the present experimental values. Chen and Crasemann[3] predict from a non-relativistic independent-particle model values at Z = 67 of $\omega_2 = 0.190$ and $f_{23} = 0.147$. Although the predicted value of ω_2 agrees well with the present experiment, the value of f_{23} is much too large, as has been found by Nix and Fink[9] in a systematic comparison of theory and experiment for f_{23} vs. Z. The 1971 non-relativistic calculations of Chen, Crasemann, and Kostroun[4] also predict values of f_{23} which exceed the trend of experimental results, although the theoretical predictions of ω_2 and ω_3 agree with the present results.

The 1979 relativistic calculations of Chen, et al[1] do not extend below Z = 70. However, a linear extrapolation to Z = 64 indicates good agreement with the present experimental values of ω_2. Extrapolation to $Z < 70$ for f_{23} is not feasible, but it would appear to result in values much larger than the present experimental ones. We are extending the present measurement technique to Z = 54 and to Z = 82 to provide a more general critical test of theory.

The origin of the rather serious disagreement between theory and experiment for f_{23} can no longer be ascribed to error in the experiments, nor can it arise from the small admixture of double vacancies from K-LL and K-LM Auger transitions, since this effect has been shown at Z = 49[10], 73[11], and 82[12] to be less than about 10% on L-fluorescence yields and is probably altogether negligible for f_{23}.

---

9) D. W. Nix and R. W. Fink, Z. Physik A273, 305 (1975)

10) P. A. Indira, I. J. Unus, P. V. Rao, and R. W. Fink, J. Phys. Atom. Molec. Phys. (London) B12, 1351 (1979)

11) J. L. Campbell, L. A. McNelles, J. S. Geiger, J. S. Merritt, and R. L. Graham, Can. J. Phys. 55, 868 (1977)

12) P. V. Rao, R. E. Wood, and V. R. Veluri, J. Phys. Atom. Molec. Phys. (London) B10, 399 (1977)

This work has been submitted for publication in Z. Physik A and presented at the Washington meeting of the American Physical Society (April, 1970) (ref. 13 in Sect. 6.0)

(B. E. Gnade, R. A. Braga, and R. R. Fink)

3.2 Experimental Measurement of Tailing Corrections in Low Energy Coincidence Intensity Determinations

A new method for the evaluation of the net intensity of each component of a partially resolved multiplet in a low energy photon (< 100 keV) coincidence spectrum is demonstrated. The method assumes only that both members of a doublet have the same peak shape which need not be known. The method does not require additional measurements and is independent of peak shapes and timing problems. We have applied this method in a problem requiring resolution of the K_{α_1} and K_{α_2} x rays in coincidence with L x rays from the decays of 10.4 h ^{165}Er and 4.68 y ^{155}Eu, described in Sect. 3.1.

Previous coincidence studies have not recognized that the correction for the K_{α_1} tail in the K_{α_2} peak gate requires that the different time structures for peak events (K_{α_2} coincidences) and tail events (K_{α_1} coincidences) must be taken into account. This difference in the time structure between events in the peak and events in the tail is taken into account in this method.

The new method was investigated with the multiparameter XX·t coincidence electronic setup illustrated by the block diagram shown in Fig. 1. In Fig. 2a (upper figure) a comparison is shown between a singles peak shape and a coincidence peak shape in a planar intrinsic Ge(HP) x-ray detector. Curve a) is the K_{α_1} and K_{α_2} doublet from the decay of 10.4 h ^{165}Er in coincidence with the L_{β_1} x ray using a broad time window ($\approx$ 500 nsec), while curve b) is the same, but using a narrow, prompt time window ($\approx$ 70 nsec). Curve c) is the singles peak shape of the 46.5 keV γ-ray from the decay of 22 y ^{210}Pb[RaD] normalized to the

K_{α_1} x-ray peak. In Fig. 2b (lower figure) a comparison is shown of the tailing from the K_{α_1} - K_{α_2} x-ray doublet in coincidence with the L_α x-ray peak in the decay of 10.4 h ^{165}Er, where curve a) is for a broad time window of $\approx$ 500 nsec. and curve b) is for a narrow, prompt time window of $\approx$ 70 nsec.

As numerical examples of this method, the coincident K x-ray spectra shown in Figs 3 and 4) from decays of 4.68 y ^{155}Eu and 10.4 h ^{165}Er, respectively, have been resolved, and values for the composition of the K_{α_2} x-ray gate G_2 have been obtained.

In gate G_2, which represents the coincident K_{α_2} x-ray peak, the contribution from the K_{α_1} tail, determined by the new method, amounts to 5.7% and 7.5% for 10.4 h ^{165}Er and 4.68 y ^{155}Eu, respectively. By fitting a singles line shape, the corrections would be 7.2% and 9.0%, respectively; ie, the new method reduces these corrections by about 20%.

This method provides a full separation of partially resolved low energy (< 100 keV) photon doublets in coincidence spectra on the assumption <u>only</u> that both members of the doublet have the same peak shape and time structure which need not be known.

A complete description of the new method and its application has been accepted for publication in Nuclear Instruments and Methods (ref. 15 in Sect. 6.0).

(B. E. Gnade, R. A. Braga, J. L. Wood, and R. W. Fink)

3.3 L-Subshell X-ray Fluorescence and Coster-Kronig Yields at Z = 54 and 82

In order to obtain reliable values at both high and low Z, we are continuing our investigation of L-subshell x-ray fluorescence and Coster-Kronig yields with the multiparameter XX·t method described above by extending the measurements to Z = 54 (Xe) and 82 (Pb) from the decays of 9.9 day ^{131}Cs and 33.4 year ^{207}Bi,

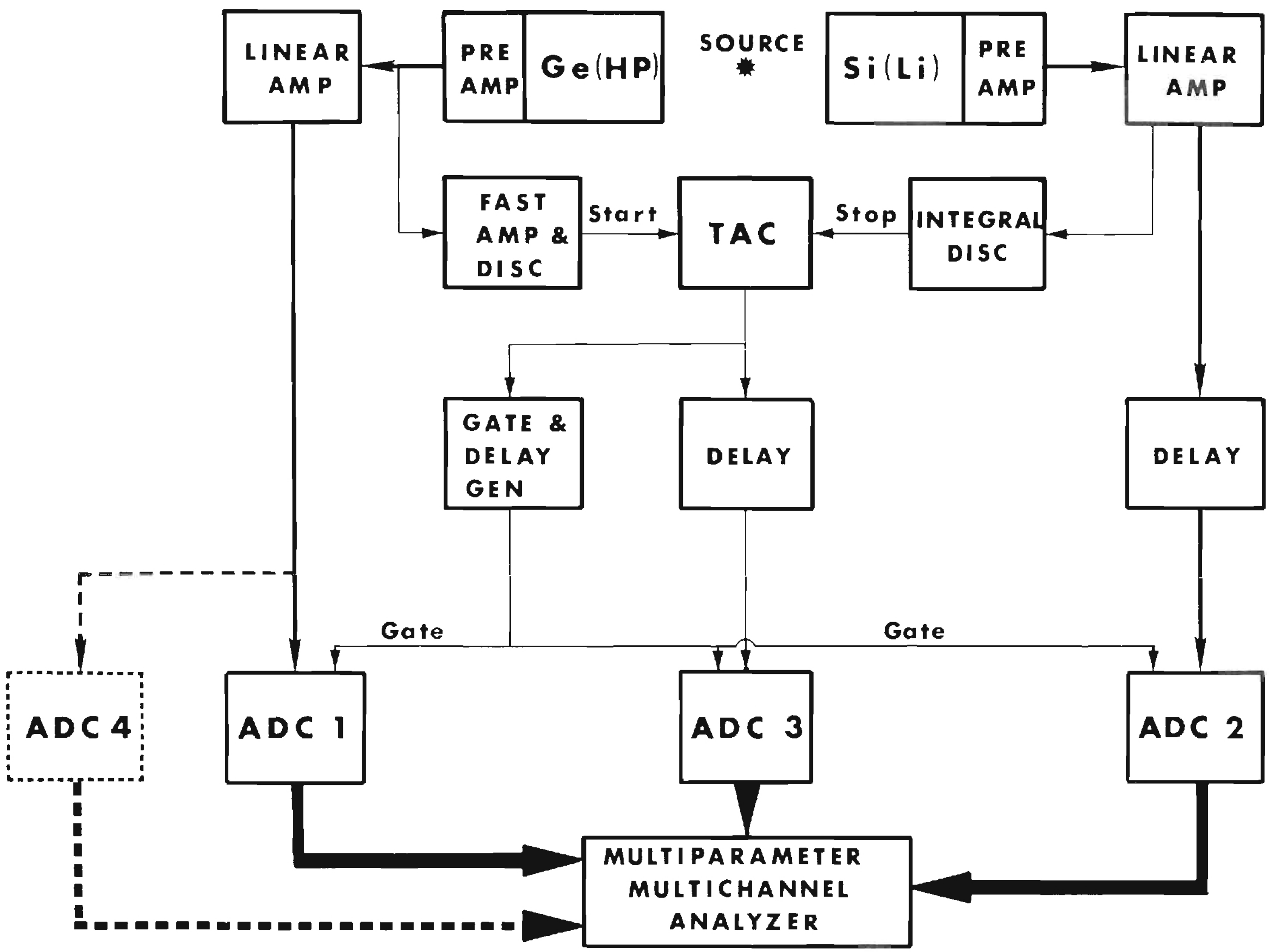
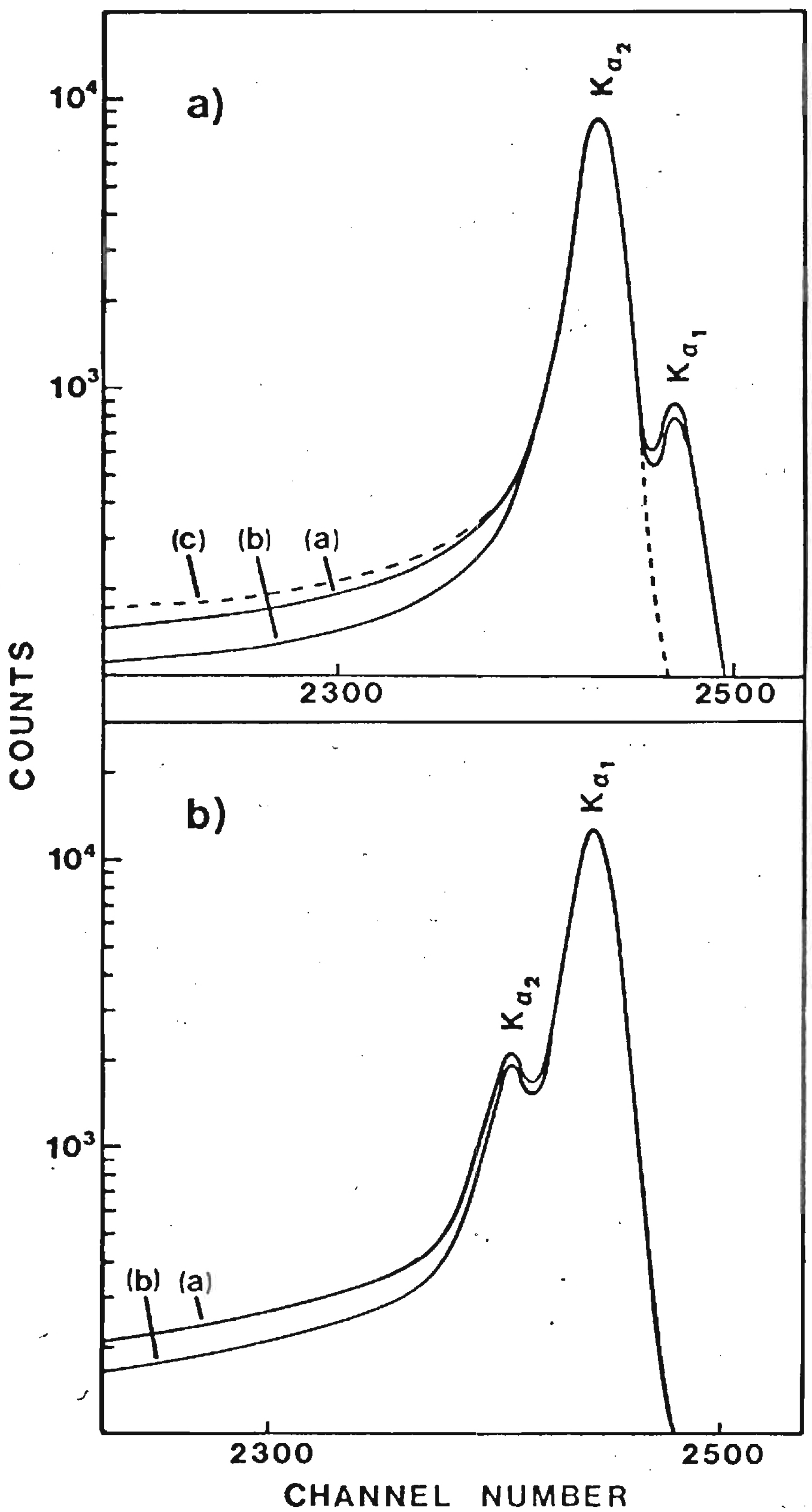
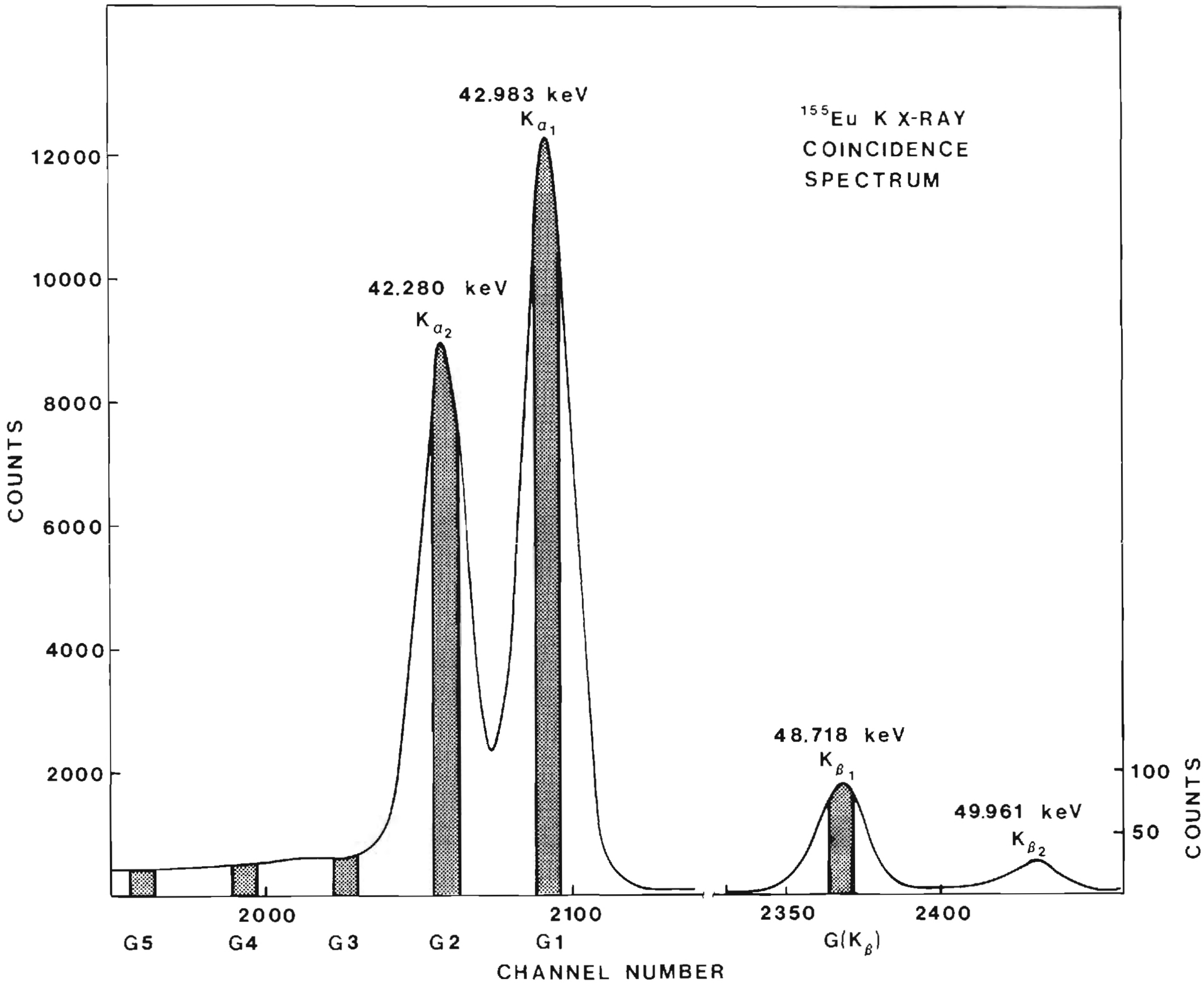

LINEAR AMP
PRE AMP
Ge(HP)
SOURCE
Si(Li)
PRE AMP
LINEAR AMP
FAST AMP & DISC
Start
TAC
Stop
INTEGRAL DISC
GATE & DELAY GEN
DELAY
DELAY
Gate
Gate
ADC 4
ADC 1
ADC 3
ADC 2
MULTIPARAMETER MULTICHANNEL ANALYZER

Fig. 1



a)
b)
K_{α_2}
K_{α_1}
(a)
(b)
(c)
10^4
10^3
2300
2500
COUNTS
CHANNEL NUMBER

Fig. 2



42.983 keV
K_{α_1}
^{155}Eu K X-RAY
COINCIDENCE
SPECTRUM
42.280 keV
K_{α_2}
48.718 keV
K_{β_1}
49.961 keV
K_{β_2}
COUNTS
12000
10000
8000
6000
4000
2000
100
50
COUNTS
2000
2100
2350
2400
G5
G4
G3
G2
G1
G(K_β)
CHANNEL NUMBER

Fig. 3

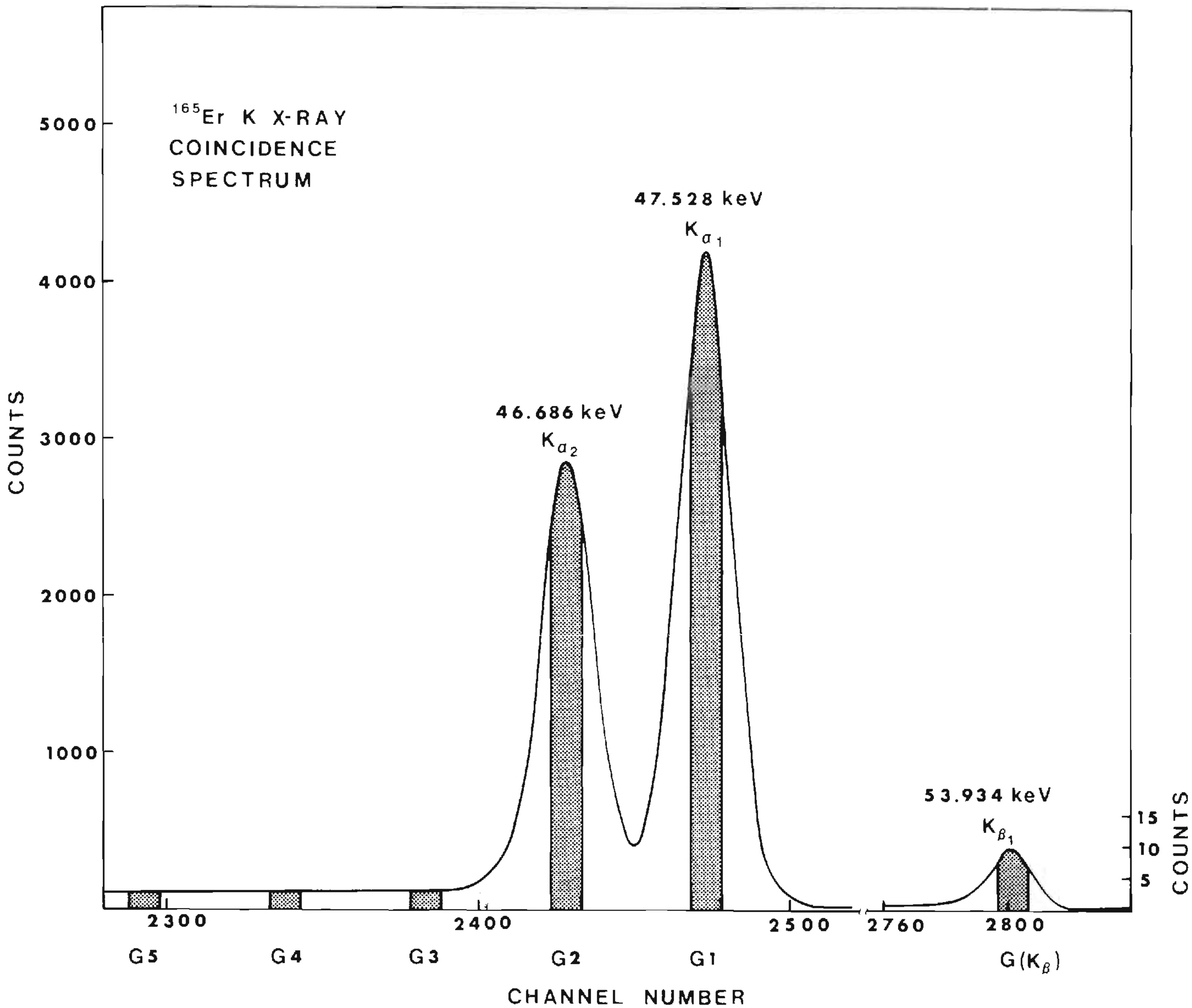

^{165}Er K X-RAY
COINCIDENCE
SPECTRUM
47.528 keV
K_{α_1}
46.686 keV
K_{α_2}
53.934 keV
K_{β_1}
COUNTS
5000
4000
3000
2000
1000
15
10
5
COUNTS
2300
2400
2500
2760
2800
G5
G4
G3
G2
G1
$G(K_\beta)$
CHANNEL NUMBER

Fig. 4

respectively. In the latter case, we plan to include the L_1 subshell results as well as the L_2 and L_3 subshells. A preliminary analysis of the first runs on ^{207}Bi gives a value of $f_{23} = 0.102 \pm 0.005$, which confirms our previous work based on a two-parameter K - L XX coincidence technique of 0.105 ± 0.011[13]. The error limits on the present work are considerably reduced by application of the new methods described above. The L_1 subshell yields at Z = 82 are of particular interest because of the few available cases that are accesible to study. The only previous measurement of the L_1 subshell of Pb from ^{207}Bi decay was in 1968 by Rao, et al.[14] and is in need of more accurate remeasurement with the new advances in equipment and techniques. This work is being carried forward primarily by Dr. Mustafa Tan, who is on a one year sabbatical leave from Atatürk University, Turkey (see Sect. 5.0).

(M. Tan, B. Gnade, R. A. Braga, and R. W. Fink)

Measurements also have been initiated on the $L_{2,3}$ subshell fluorescence and Coster-Kronig yields at Z = 54 (Xe) from the electron capture decay of 9.9 d ^{131}Cs. This source is prepared by irradiation of approximately 10 g natural $Ba(NO_3)_2$ in the Georgia Tech Research Reactor at 10^{13} n/cm^2·sec for 8 hours. The ^{131}Cs daughter of 12.0 d ^{131}Ba is radiochemically separated by a series of $BaCl_2 \cdot H_2O$ precipitations[15] to give a carrier-free, solids-free source, which is drop-evaporated onto a Mylar backing. The first ^{131}Cs source was prepared and studies to check the radiochemical separation procedure and determine the

---

13) D. W. Nix and R. W. Fink, Z. Physik A273, 305 (1975)

14) P. V. Rao, R. E. Wood, J. M. Palms, and R. W. Fink, Phys. Rev. 178, 1997 (1969)

15) R. W. Fink and B. L. Robinson, Phys. Rev. 98, 1293 (1955)

---

decontamination factor. Previous work on the L-shell of xenon (Z = 54) consists of the determination of the mean fluorescence yield $\bar{\omega}_L$ (0.10 ± 0.01)[15,16], and the very early work of P. Auger in 1923 in which gaseous Xe in a cloud chamber was fluorescently excited with x rays resulting in the discovery of the Auger effect[17]. Much more recently, the L-subshells were studied[18] and values of $\omega_3 = 0.099 \pm 0.002$, $\nu_2 = 0.106 \pm 0.007$, and $\nu_1 = 0.09 \pm 0.03$ determined by fluorescent excitation of gaseous Xe in a multiwire proportional counter. The present work takes advantage of the new multiparameter XX·t techniques and experimental tailing correction determination to determine the $L_{2,3}$ Coster-Kroing transition probability f_{23} for the first time, as well as values of the subshell-fluorescence yields ω_2 and ω_3. No prior measurements exist below Z = 63 with commensurate accuracy. The results should encourage extension of the recent relativistic theoretical calculations of Chen, Laiman, Crasemann, Aoyagi, and Mark[1] to values below Z = 70. The work constitutes the M.S. thesis of Mr. W. S. Lewis and is expected to be completed during 1979.

(W. S. Lewis, B. E. Gnade, R. A. Braga, and R. W. Fink)

---

16) K. Hohmuth and G. Winter, Phys. Lett. 10, 58 (1964)

17) P. Auger, J. Phys. Radium 6, 205 (1925)

18) M. Hribar, A. Kodre, and J. Pahor, Z. Physik A280, 227 (1977 and Physica 92C, 143 (1977)

3.4 Tables for Handbook of Spectroscopy, Vol. 3

We have updated our tables of K-, L-, and M-shell x-ray and Coster-Kronig transition yields for the forthcoming Vol. 3 of the Handbook of Spectroscopy (ref. 8 in Sect. 6.0). R. W. Fink served on the international advisory board for this handbook and has arranged for additional chapters on thermal neutron capture cross sections (ref. 7 of Sect. 6.0) and 14 MeV neutron activation cross sections by S. M. Qaim of Jülich, West Germany.

(R. W. Fink)

3.5 Properties of Si and Ge Semiconductor Detectors for X-ray Spectrometry

The characteristics of silicon and germanium semiconductor x-ray detectors of various designs (disk, top hat, grooved, and ion implanted types) have been reviewed, including discussion of sensitive area and depth, metallic- and dead-layers. The effects of electronic operating conditions and timing requirements on spectral peak shapes (tailing), resolution, and efficiency in singles and in coincidence measurements are reported. The response to mono-energetic photons is discussed, including second-order x-ray spectral effects, such as the low-energy plateau, escape peaks, the continuum around the full-energy peak, summing and sum peaks, and effects of collimation. Various methods of measuring relative and absolute detector efficiencies for photons from about 200 eV to 140 keV in energy are summarized, and a useful table is presented of long-lived radioactive sources suitable for calibration of energy and efficiency curves of x-ray detectors, in which the current best values of halflife, photon energies, and the absolute number of photons emitted per 100 decays are tabulated. Finally, some recently reported advances in detectors, electronic systems, and a new method of unfolding partly-resolved doublets (e.g. $K_{\alpha 1}$ and $K_{\alpha 2}$ lines) in coincidence spectra are summarized. This work was presented as the opening invited paper at the National Bureau of Standards, April 23, 1979, at the Workshop on Energy Dispersive X-ray Spectroscopy. The full review article will appear in an NBS hardbound publication of the proceedings of this symposium.

(R. W. Fink)

4.0 MISCELLANEOUS TOPICS

4.1 CDC-Cyber 70/74 Computer Codes

The computer codes "PHINT" and "ODDA" (written by O. Scholten, K.V.I., Groningen, The Netherlands) have been adapted for operation on the Georgia Tech CDC Cyber 70/74 computer. These codes calculate energies and eigenvalues for positive and negative parity states for even-A and odd-A nuclei, respectively, in the framework of the interacting boson approximation model. The energies and eigenvalues are calculated by diagonalization of the IBA Hamiltonian in the spherical basis representation. (R. A. Braga)

4.2 Equipment

4.2.1 An Inexpensive Pulser for Adjustment of Sub-nanosec Walk in Timing Circuits

An inexpensive pulse generator capable of providing narrow (< 10 nsec FWHM: ± 1.2V) pulses is described. In this application, the pulser is used to adjust the walk in calibrating amplitude and rise/time compensated (ARC) timing units both at UNISOR and in our on-campus laboratories. A walk of of 22 psec between 0 db and -40 db with a maximum spread of 220 psec over the full range is observed. The electronic schematic of the 10 nsec pulser circuit, providing a -1.2 volt output pulse, is shown in Fig. 5. (All capacitances are in μf and all resistances are in ohms.) To obtain a + 1.2 volt pulse, the addition of one of the two remaining unused NAND gates is required. The use of this pulser is indicated in Fig. 6 in a block diagram of the experimental setup for calibrating an ARC timing unit, and the resulting TAC spectra are shown in Fig. 7 for attenuator settings of 0, -10, -20, -30, and -40 db.

This development has been accepted for publication in Nuclear Instruments and Methods (see ref. 15 in Sect. 6.0). (R. A. Braga, G. E. O'Brien and R.W.Fink)

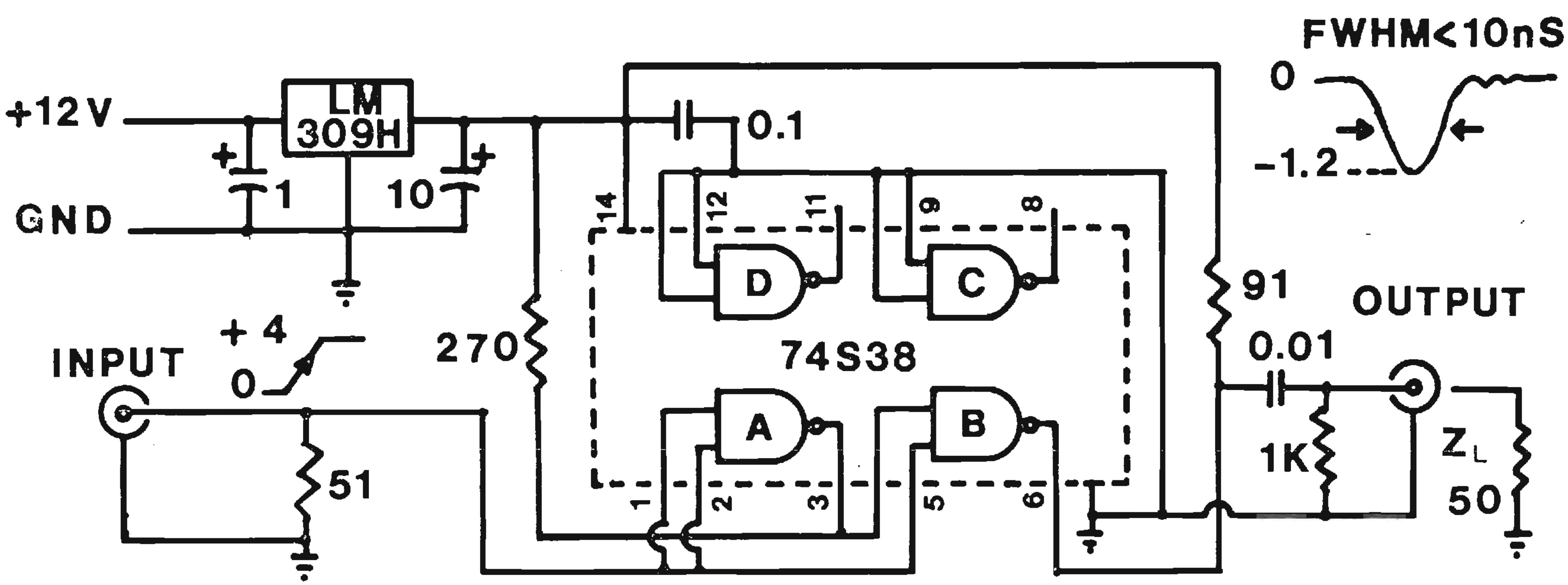

FWHM<10nS
0
-1.2
+12V
GND
LM
309H
1
10
0.1
14
12
11
9
8
D
C
91
OUTPUT
0.01
74S38
270
+4
0
INPUT
A
B
51
1K
Z_L
50
1
2
3
5
6

Fig. 5

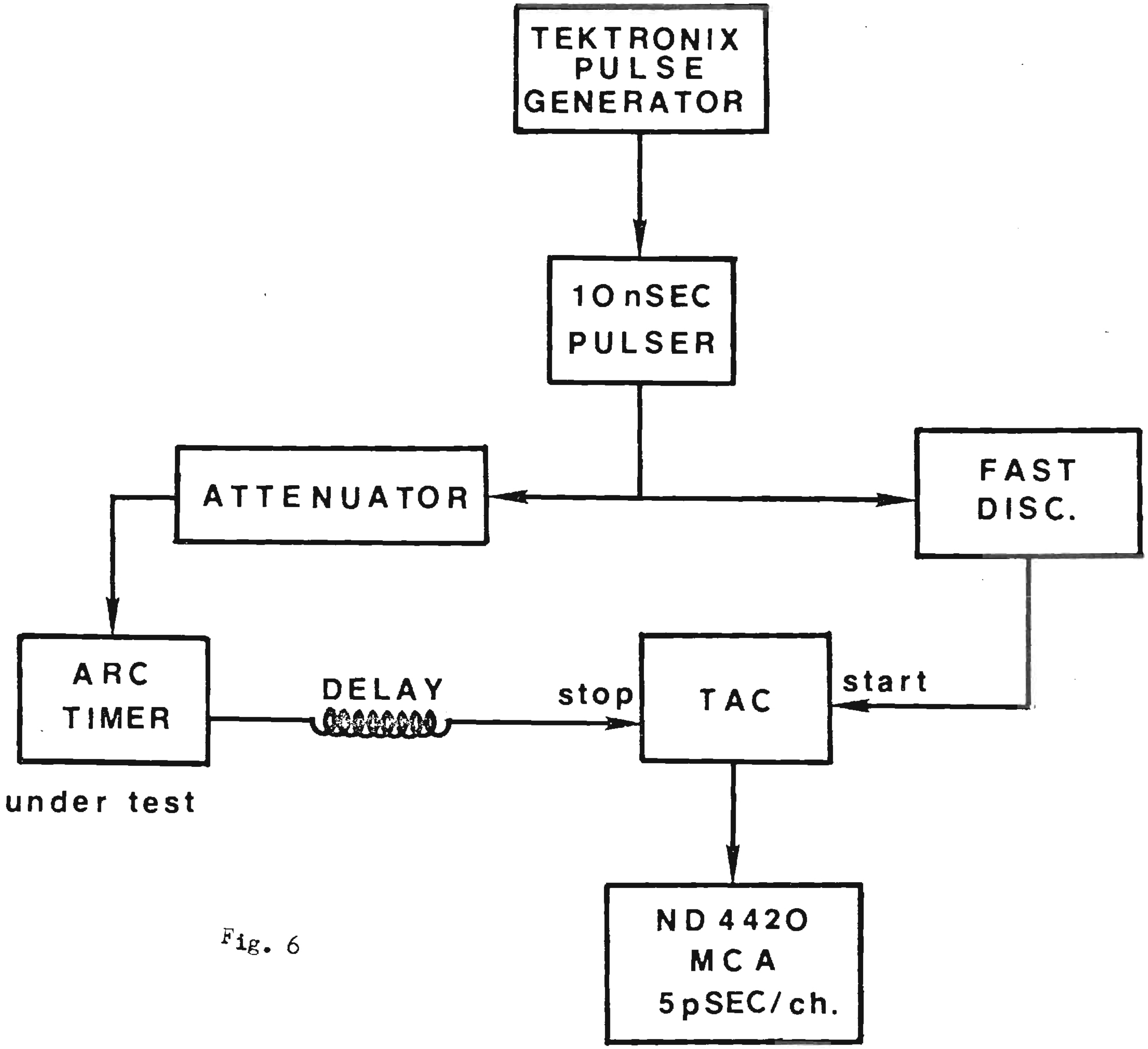
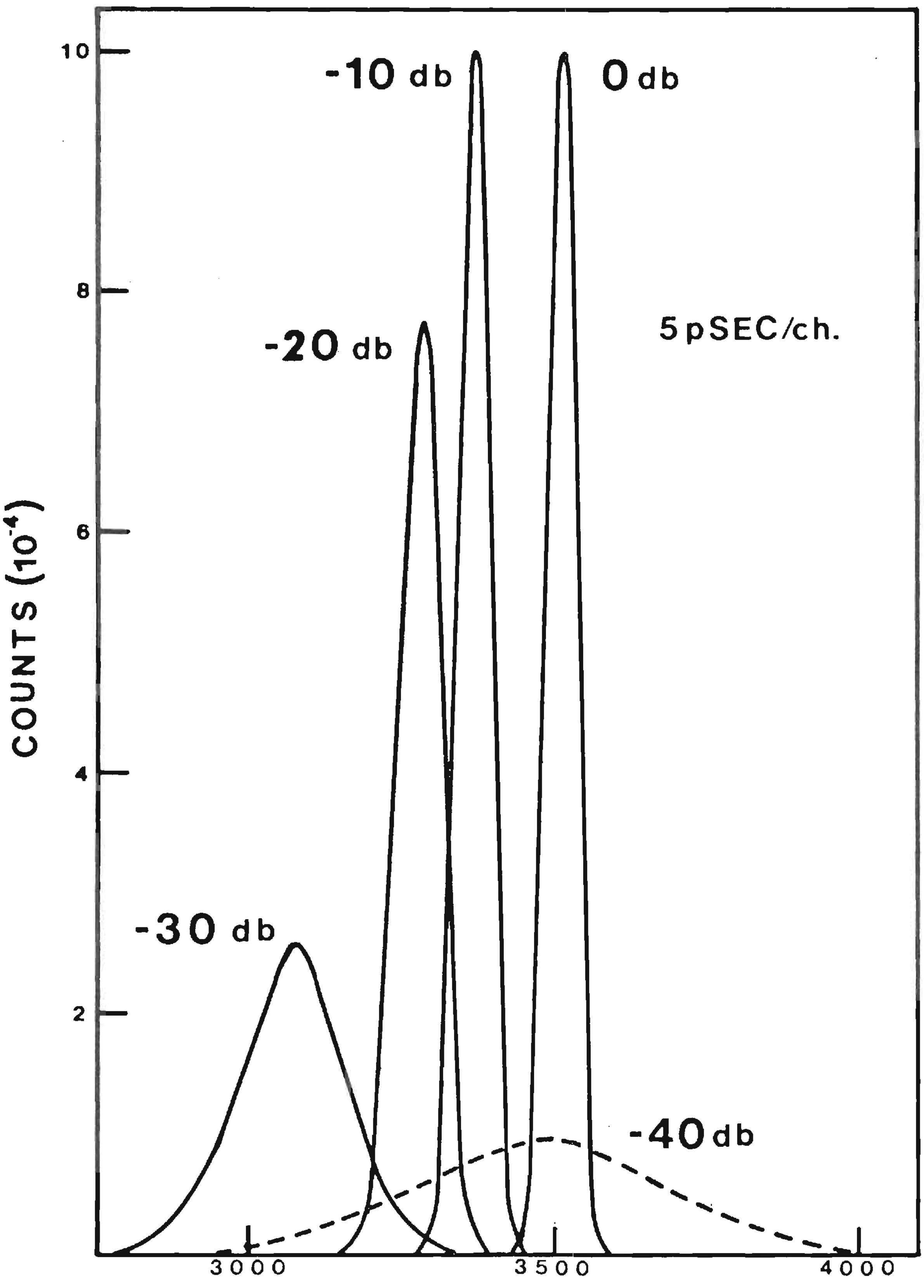

TEKTRONIX PULSE GENERATOR
10 nSEC PULSER
ATTENUATOR
FAST DISC.
ARC TIMER
under test
DELAY
stop
TAC
start
ND 4420 MCA 5 pSEC/ch.

Fig. 6



10
8
6
4
2
COUNTS (10^{4})
-10 db
0 db
-20 db
5 pSEC/ch.
-30 db
-40 db
3000
3500
4000
CHANNEL NUMBER

Fig. 7

4.2.2. Detectors and Shop Fabrication of UNISOR Items

During the past year, three detectors had to undergo repair/replacement. Our large-volume 5.3% Princeton Gamma-Tech Ge(Li) detector had to be reconditioned as a result of a vacuum leak in the cryostat. In addition, both our ORTEC Ge(HP) and Kevex Si(Li) detectors were returned to their respective manufacturers for replacement of crystals that would no longer hold bias.

During the week of August 15-22, 1979, another of our three Si(Li) detectors suffered a total loss. It developed a large vacuum leak which caused it to use up 31 liters of liquid nitrogen in less than a week. This in turn caused the cryostat to warm up, releasing the gases that had been accumulating for many years in the molecular sieves and creating an internal pressure high enough to blow out the Be window. The Be window and the plastic protective cover were found on the floor on the morning of August 21, one day before the scheduled weekly filling with liquid nitrogen. The detector is a total loss and will have to be replaced with a new crystal at a cost of \$2000 to \$4000.

Our Chemistry Machine Shop fabricated two radioactive-source "Quick Change" assemblies for on-line operation at UNISOR.

5.0 PERSONNEL

Senior Staff:

Prof. R. W. Fink, Principal Investigator
(1/4 time, 12 months)

Dr. J. L. Wood, Research Scientist, Co-principal Investigator

(October 1, 1972-present; full-time DOE, 12 months, except January, 1979, on leave-of-absence while at GSI, Darmstadt, West Germany)

Dr. R. A. Braga, Research Associate
(October 1, 1972-present; 63% DOE research + 37% teaching for the School of Chemistry, 12 months)

Dr. W. R. Western, Research Associate
(November 1, 1976 - January 31, 1979; presently at Nuclear Data Corp.)

Dr. Mustafa Tan, Asst. Prof. of Physics at Atatürk University, Turkey
(December 18, 1978-present, full-time on sabbatical leave from Atatürk University, Turkey, and supported by 1/3 time grant from the Turkish Government. No support in USA.)

Graduate Students:

Mr. Brude Gnade (Chemistry). Continuing Ph.D. thesis research
(1/2 time research assistantship DOE, 12 months)

Dr. Marvin Grimm (Physics) Graduate December, 1978 with Ph.D. based on UNISOR research. Presently at Dept. of Physics, University of Georgia, Athens, Georgia.

Mr. Chris Papanicolopulos (Physics). Continuing Ph.D. thesis work
(1/2 time research assistant from June 1, 1975 to March 15, 1979; leave-of-absence March-September, 1979; then 1/2 time research assistant DOE September 1, 1979-present)

Mr. W. S. Lewis (Chemistry). Continuing M.S. thesis work (not supported by DOE contract)

Mr. Guy J. Tonti, Jr. (Chemistry) Terminated March, 1979.

Special Problems Research Students:

Mr. Paul Semmes (Chemistry). June, 1979-present. Senior problem: Analysis of UNISOR ^{201}Po data

Mr. Gary Schweiger (Nuclear Engineering). August, 1979-present. Completing M.S. degree in N.E. Special Problem: Production of ^{18}F in the Georgia Tech Nuclear Reactor for synthesis of 2-fluoro-2-deoxy-D-glucose. Plans to join the nuclear chemistry group after completing of M.S. in January, 1980, to work toward Ph.D. in nuclear chemistry.

6.0 LIST OF PUBLICATIONS, PRESENTATIONS AT CONFERENCES AND MEETINGS, AND OUTSIDE SEMINARS 1979

1) "The Use of Nuclear Systematics in the Interpretation of Nuclear Structure Far from the Beta-Stable Region," J. L. Wood, Proc. Int. Workshop on Gross Properties of Nuclei and Nuclear Excitations VII, Hirschegg, Kleinwalsertal, Austria, Jan. 15-27, 1979, INKA-Conf. 79-001-067 (Institut für Kernphysik, Technische Hochschule Darmstadt, Feb. 1979).

2) "The Use of Systematics in the Interpretation of Nuclear Structure Far from the Beta-Stable Region," J. L. Wood, Proc. Int. Symp. on Future Directions in Studies of Nuclei Far from Stability, Nashville, Tennessee, Sept. 9-13, 1979, edited by J. H. Hamilton (North-Holland Publishing Co., Amsterdam, in press).

3) "Decay of ^{195}Tl(1.13 h) to ^{195}Hg," G. M. Gowdy, J. L. Wood, and R. W. Fink, Nuclear Physics. A312, 56-80 (1978).

4) "Halflives and Decay of ^{197}Pb Isomers," M. S. Rapaport, R. W. Fink, L. L. Riedinger, L. L. Collins, and G. D. O'Kelley, Nucl. Phys. A315, 163-168 (1979).

5) "A Fast Beta Transition in ^{183}Pt and the Systematics of Nilsson States in the N = 105 Isotones," A. Visvanathan, E. F. Zganjar, J. L. Wood, R. W. Fink, L. L. Riedinger, and F. W. Turner, Phys. Rev. C19, 282-284 (1979).

6) "L X-ray Yields from Double-Vacancy States in Indium," P. A. Indira, I. J. Unus, P. V. Rao, and R. W. Fink, J. Phys. (London) Atom.-Molec. Phys. B12, 1351-1356 (1979).

7) "Decay of Mass-Separated ^{197}Tl (2.83 h) to ^{197}Hg," R. A. Braga, J. L. Wood, G. M. Gowdy, and R. W. Fink, Phys. Rev. C19, 2305-2313 (1979).

8) "Orbital Electron Capture Ratios in the Decay of ^{205}Pb," J. G. Pengra, H. Genz, and R. W. Fink, Nucl. Phys. A302, 1-11 (1978).

9) BOOK CHAPTER:
"Thermal Neutron Activation Cross Sections," R. W. Fink, in Handbook of Spectroscopy, Vol. 3, edited by J. W. Robinson (CRC Publishing Co., West Palm Beach, Florida, 1980, in press). [ORO-3346-206]

10) BOOK CHAPTER:
"Tables of Experimental Values of X-ray Fluorescence and Coster-Kronig Yields for the K-, L-, and M-Shells," R. W. Fink and P. V. Rao, in Handbook of Spectroscopy, Vol. 3, edited by J. W. Robinson (CRC Publishing Co., West Palm Beach, Florida, 1980, in press). [ORO-3346-202]

11) BOOK CHAPTER:
"Analysis of Zinc and Copper," R. W. Fink and J. H.Carden, Chapt. 2 in Zinc and Copper in Medicine, edited by R. M. Sarper and Z. A. Karcioglu (C. C. Thomas Publishers, Springfield, Illinois, 1980, in press).

12) BOOK CHAPTER AND INVITED PAPER:
"Properties of Silicon and Germanium Semiconductor Detectors for X-ray Spectrometry," R. W. Fink in Symposium on Energy-Dispersive X-ray Spectrometry, National Bureau of Standards, April, 1979, in press. [ORO-3346-231]

13) "An Improved Measurement of the $L_{2,3}$-Subshell X-ray Fluorescence and Coster-Kronig Yields at Z = 64 and 67," B. E. Gnade, R. A. Braga, and R. W. Fink, Bull. Am. Phys. Soc. 24, (1979) and Z. Physik (submitted July, 1979). [ORO-3346-233]

14) "Determination of Corrections for Tailing in Low-Energy Coincidence Intensity Measurements," B. E. Gnade, R. A. Braga, J. L. Wood, and R. W. Fink, Nucl. Instr. Meth. 164, 163-167 (1979) and Bull. Am. Phys. Soc. 24, 754 (1979). [ORO-3346-224]

15) "An Inexpensive Pulser for the Adjustment of Subnanosec Walk in Timing Circuits," R. A. Braga, G. E. O'Brien, and R. W. Fink, Nucl. Instr. Meth. (in press, 1979). [ORO-3346-230]

16) "M4 Isomerism and the Observation of the $s_{1/2}$ Shell-Model Intruder State in ^{201}Bi," R. A. Braga, W. R. Western, J. L. Wood, and R. W. Fink, Bull. Am. Phys. Soc. 24 (1979); Nucl. Phys. A (to be published). [ORO-3346-235]

17) "Studies of Z = 81 Transitional Nuclei. I. ^{197}Pb Decay," L. L. Collins, L. L. Riedinger, G. D. O'Kelley, C. R. Bingham, M. S. Rapaport, J. L. Wood, and R. W. Fink, Phys. Rev. C (1979) (Submitted). [ORO-3346-221]

18) "Studies of Z = 81 Transitional Nuclei. II. ^{193}Pb and ^{195}Pb Decay," L. L. Collins, L. L. Riedinger, G. D. O'Kelley, J. L. Wood, and R. W. Fink (to be submitted) [ORO-3346-222]

19) J. L. Wood, invited talk on UNISOR program, Gordon Research Conference on Nuclear Chemistry, New London, N. H., June 18-22, 1979.

20) "Decay Scheme Studies of Nuclear Structure in Very Neutron-Deficient Nuclei Using On-Line Isotope Separators," J. L. Wood, invited talk at Am. Phys. Soc. Fall Meeting of the Division of Nuclear Physics, Knoxville, Tenn., Oct. 18-20, 1979; Bull. Am. Phys. Soc. 24 (1979) (in press). [ORO-3345-234]

21) "Experimental Particle-Core Coupling Systematics," J. L. Wood, Bull. Am. Phys. Soc. 24, 591 (1979) (Washington, D. C., April 23, 1979).

22) "Excited 0+ States, Nuclear Isomerism, and Odd-Nuclear Coupling," J. L. Wood, Bull. Am. Phys. Soc. 23, 945 (1978).

23) "Nuclear Systematics," J. L. Wood, Seminar presented at University of Toronto, March 2, 1979.

ORO–3346–242

G-33-645

NUCLEAR CHEMISTRY RESEARCH AND SPECTROSCOPY WITH RADIOACTIVE SOURCES

Sixteenth Annual Progress Report

U. S. Department of Energy

Contract DE–AS05–76ERO–3346

R. W. Fink

Professor of Chemistry & Principal Investigator

October 31, 1980

GEORGIA INSTITUTE OF TECHNOLOGY

SCHOOL OF CHEMISTRY

ATLANTA, GEORGIA 30332

1980

Tel. (404) 894–4030

NUCLEAR CHEMISTRY RESEARCH AND SPECTROSCOPY WITH RADIOACTIVE SOURCES

Sixteenth Annual Progress Report

U. S. Department of Energy

Contract DE-AS05-76ERO-3346

R. W. Fink

Professor of Chemistry and Principal Investigator

Telephone (404) 894-4030

October 31, 1980

School of Chemistry

Georgia Institute of Technology

Atlanta, Georgia 30332

TABLE OF CONTENTS

Table of contents...

1.0 INTRODUCTION

Owing to the extended shutdown of UNISOR to install an on-line laser spectroscopy system and to shutdowns of the Oak Ridge Isochronous Cyclotron for modification to accept heavy ion injection from the 25 MV folded tandem accelerator (HHIRF), our first UNISOR runs in more than 16 months did not begin until late July, 1980. Therefore, we used this period of time to reduce almost completely the large backlog of unanalyzed UNISOR data accumulated from previous runs; in particular, our investigations of the A = 201 mass chain (5 runs) and of ^{187}Au decay were carried out.

Our goal remains to establish the detailed nuclear spectroscopy (including the weak γ-ray transitions and conversion electrons) of nuclei in regions near the Z = 82 closed shell. Such completeness in the spectroscopic measurements is essential in determining the systematic trends which underlie the interpretation of nuclear structure far from stability. In view of this requirement, our July, 1980, run [^{181}Ta(^{12}C, 6n)^{187}Au] to study the γ-rays in the decay of 8.4 min ^{187}Au produced data of the best statistical quality ever obtained at UNISOR.

Considerable progress has been made this year in the systematic investigation of the Interacting Boson-Fermion Approximation (IBFA) predictions for odd-A gold isotopes (A = 185-197) and their comparison with current experimental results. The latest version of the computer codes PHINT and ODDA has supplanted the earlier one on the CDC Cyber 70/74 Georgia Tech computer. In addition, the IBFA code NPBOS was implemented this year on the Georgia Tech computer.

Our completed investigation of the highly retarded M4 transitions from the $s_{1/2}$ intruder isomeric states in ^{199,201}Bi, on which a manuscript will shortly appear in Nuclear Physics A, was cited by the visiting UNISOR review committee as one of the major achievements in UNISOR research in the past year.

On campus, the three-parameter XX·t, Xce-·t, and Xγ·t x-ray coincidence measurements implemented on our ND-4420 multiparameter, multichannel analyzer are similar to coincidence measurements at UNISOR and provide excellent training for our graduate students and postdoctoral investigators who will then later participate in UNISOR research. Moreover, such coincidence measurements provide experience in handling the more difficult electronic timing problems inherent in low-energy photon and electron spectroscopy which is becoming exceedingly important at UNISOR.

These XX·t three-parameter measurements with high resolution Si(Li) and Ge(HP) x-ray detectors are used to obtain the L_1-subshell yields ω_1, f_{12}, and f_{13} and L_2-subshell Coster-Kronig transition probability f_{23}. The experimental data on L_1-subshell yields are sparse because of the lack of suitable radioactive sources that produce L_1 atomic vacancy states. There is a need to collect reliable experimental information for comparison with the theory. In the case of f_{23}, the most recent relativistic calculations indicate that our current experimental values agree well with the theoretical estimates. Recent advances in the analysis of the coincidence spectra to measure these yields are effectively employed to complete a comprehensive set of measurements on Z = 82, in order to obtain all the parameters of interest , ie, the fluorescence yields ω_i, the Coster-Kronig yields f_{ij}, and the radiative branching ratios s_i.

2.0 Nuclear Spectroscopy Studies

2.1 Decay of ^{201}Po and ^{201}At Isobars

An analysis of the decay of ^{201m,g}Po (9 min, 14 min) is nearing completion under the coordination of Dr. R. A. Braga. The activity was produced at UNISOR by bombarding natural Ir with 113 MeV ^{14}N ions, and the data acquired includes γ-ray and ce$^-$ singles, $\gamma\gamma\cdot t$ coincidence, and γ-ray and ce$^-$ multispectral data. Prior to our study the most comprehensive investigation of the excited states in ^{201}Bi was that of Korman, et. al.[1)].

[1] A. Korman, D. Chlebowska, T. Kempisty, and S. Chojnacki, Acta Phys. Polon. (Warsaw) B7, 141 (1976)

In Table I we list the γ-rays assigned to transitions in ^{201}Bi, along with their intensities and tentative multipolarities, and Table II is a listing of observed coincidence relationships. From these data, we construct the decay scheme shown in Fig. 1. (A number of weak, unassigned γ-rays observed in the spectra are not listed in the tables nor shown in Fig. 1.) A major portion of this scheme is the band built upon the $s_{1/2}$ shell-model intruder state and the M4 isomeric transition depopulating this state in ^{201}Bi, (see Sect. 2.2). In addition we observe a level structure populated by the decay of the high-spin 13/2+ isomeric state of ^{201m}Po (9 min),(shown in Fig. 1, right side), as well as a structure fed by the decay of the 3/2- ground-state of ^{201g}Po (14 min) (shown in Fig. 1, left side). We observe both ^{201}Po isomers, since the high spin upper state, produced almost exclusively in the heavy ion reaction, feeds the lower spin ground-state via an isomeric cascade.

This work is part of a UNISOR effort to investigate the systematics of the light Z = 83 nuclei. It is of particular interest to study the coupling of the single-particle or hole states to the even-even Pb or Po cores. In this description, the 5/2-, 7/2- and the 11/2-, 13/2-, 15/2-

Fig. 1 - Partial decay scheme of ^{201}Bi populated in the decay of $^{201m,g}Po$ (9 min, 14 min). Relative intensities appear in Table I, along with tentative multipolarity assignments. The right side of the decay scheme is populated from the decay of the 13/2+, 9 min ^{201m}Po isomer, while the left-side arises from decay of the 3/2-, 14 min ^{201g}Po ground state.

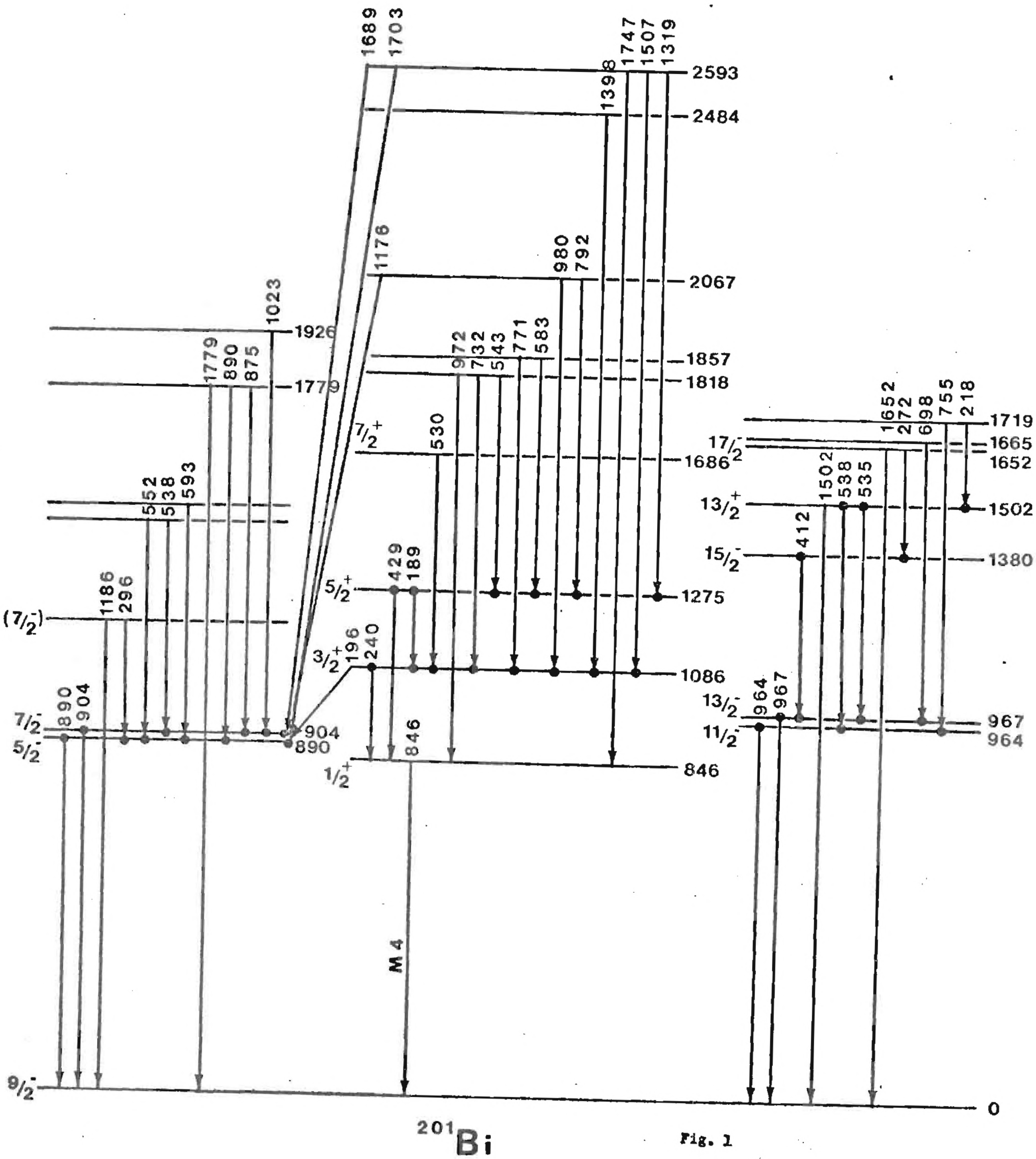

2593
2484
2067
1926
1857
1779
1818
1719
1665
1652
1686
1502
1380
1275
1086
904
890
967
964
846
0
M4
201Bi

Fig. 1

state in ^{201}Bi result from the coupling of the $h_{9/2}$ single proton state to the 2+ one-phonon and 4+ two-phonon states of the ^{200}Pb core. The resulting coupling scheme can also be compared to the Z = 81 proton-hole system ($\pi h^{-1}_{9/2} \otimes {}^{200}Pb \rightarrow {}^{199}Tl$). Upon completion of this study, publication is planned in Nuclear Physics A.

Also this year we have continued our investigation of the decay of ^{201}At. This is part of an effort to obtain information on excited states of Po isotopes. These comprise part of a region which forms a completely new family of transitional nuclei and provide tests for models and concepts that have been developed to describe nuclei with $Z \leqslant 80$. In particular, excited states of the odd-mass Po isotopes, and especially the low-spin states due to the coupling of the $i_{13/2}$ unpaired neutron to the core, would reveal the shapes of the nuclei, the location of the Fermi energy, and the validity of the Meyer ter Vehn triaxial rotor model in this region.

Since ^{201}At decays via an alpha branch as well as by β^{+}/EC decay, some information on levels in ^{197}Bi as well as its decay is expected. Activities of ^{201}At were produced via the $^{nat}Ir(^{16}O,6n)$ reaction at UNISOR. The data acquired so far consist solely of γ-ray multispectral singles. The analysis of these data has resulted in the identification of several γ-rays associated with the ^{201}At decay. The γ-rays observed at 494, 763, and 849 keV decay with halflives ranging from 1.2 to 1.7 min, consistent with the previously-reported halflife of 1.5 min reported for ^{201}At[2], while several others decay with a halflife consistent with ^{197}Bi decay (6.4 min)[3] (10 min[4]). We note that the decay curves we obtain for

[2] P. Hornshøj, P. G. Hansen, B. Jonson, Nuclear Phys. A230, 380 (1974)
[3] M.S. Rapaport, in Ann. Prog, Rept. ORO-3346-173 (edited by R.W. Fink); p. 22 (1975)
[4] Y. LeBeyec, M. Lefort, J. Livet, N.T. Porile, and A. Siivola, Phys. Rev. C9, 1091 (1974)

the γ-rays associated with ^{201}At decay exhibit curvature typical of a growth and decay relationship. We believe that this shape of the decay curves is the result of the feeding of the ^{201g}At ground-state by some unknown isomeric state decay. Additional analysis is in progress, as well as a planned $X\gamma \cdot t$ experiment, in order to distinguish these γ-rays associated with ^{197}Bi following the alpha decay of ^{201}At from those belonging to ^{201}Po from the β^+/EC decay branch. (R. A. Braga and P. B. Semmes)

Table I - Gamma rays assigned to ^{201}Bi populated in the decay of $^{201m\ g}$Po (9 min, 14 min)

Energy (keV)		Intensity (relative)	Multipolarity
188.7	3	7.76	M1 + E2
195.8	3	0.54	(E1)
217.5	5	0.66	M1 + E2
240.1	2	70.38	M1 + E2
272.2	3	7.36	
296.0	6	1.90	
411.9	2	33.56	
428.1	2	13.24	E2
529.6	5	10.58	(E1)
534.7	6	10.58	
537.4	3	29.19	
543.8	5	3.59	
551.8	3	7.67	
583.3	3	5.48	
593.1	2	15.07	M1
697.6	5	4.67	
754.4	3	7.32	
771.7	5	4.46	M1
791.3	4	14.21	
846.2	2	8.35	M4
874.7	4	4.86	
890.2	2	98.10	E2
904.3	2	50.61	
964.1	3	81.71	
967.6	3	100	
978.7	5	4.54	
1175.2	3	10.59	
1186.9	4	18.93	M1
1398.3	5	5.35	
1502.1	8	3.53	

732, 972, 1023, 1319, 1507, 1652, 1689, 1703, 1747, and 1779 keV observed only in coincidence.

Table II - Gamma-ray Coincidence in ^{201}Bi from decay of ^{201mg}Po (9 min, 14 min)

Gate	coincidences observed
189	240, 543, 583, 792, 1319
218	964
240	189, 530, 732, 771, 980, 1398, 1507
272	412, 967
296	890
412	272, 967
429	583, 792
530	240
535	218, 967
538	218, 904, 964
543	189, 240
552	890
583	189, 240, 429
593	890
698	967
755	964
771	240
792	189, 240, 429
875	904
890	196, 296, 552, 593, 890, 1176
904	538, 875, 1023, 1689
964	538, 755
967	272, 412, 535, 698
980	240
1176	890
1398	240
1507	240
1689	904
1703	890

2.2 Slow M4 Transitions in ^{199,201}Bi and the $s_{1/2}$ Intruder State

The completed study of the band built upon the 1/2+ shell-model intruder state in ^{199,201}Bi and of the 846 keV M4 isomeric transition depopulating this state in ^{201}Bi has been accepted for publication in *Nuclear Physics A* (ref. 1 in Sect. 8.0 below). In addition to being the only known "ℓ-forbidden" M4 transition in odd-A nuclei, the isomeric transition in ^{201}Bi appears to be further hindered because it is a hole $\rightarrow$ particle transition.

2.3 Decay of ^{203}At

While the investigation of the decay of ^{203}At (7 min) remains a priority project, no data in addition to the previously measured γ-ray singles spectrum, have been obtained to date, owing to the extended UNISOR and ORIC shutdown periods. A run is scheduled for the latter part of 1980. This problem had been part of the doctoral thesis of Mr. Chris Papanicolopulos, who has resigned, and will be continued by Mr. Paul Semmes and other members of the nuclear chemistry group.

2.4 Decay of ^{187}Au (8.4 min)

The detailed study of the decay of ^{187m,g}Au to ^{187}Pt has been continued with a recent successful $\gamma\gamma\cdot t$ coincidence experiment. This was the first time that gold isotopes were mass separated at UNISOR, made possible by the development of a new high temperature ion source by R. L. Mlekodaj and using the ^{181}Ta(^{12}C^{+4},6n)^{187}Au reaction of 95 MeV. Preliminary analysis indicates that these data represent the highest quality (both in statistics and in resolution) ever taken on a single isotope at UNISOR, amounting to approximately 2×10^7 $\gamma\gamma\cdot t$ events.

A preliminary decay scheme, Fig. 2, was developed by Marvin Grimm as part of his PhD thesis[5]. There are numerous assignments in his scheme that are in apparent disagreement with the recent publication of Braham, et al.[6] It is hoped that the present work, and our planned ce $^{-}\gamma\cdot t$ coincidence experiments will be able to resolve these discrepancies, in order to better our understanding of the structure of the odd-mass Pt isotopes.

A preliminary experiment, mentioned in last year's annual report, ORO-3346-236 (1979), indicated that a short-lived isomer of ^{187m}Au (< 1 sec) may exist. We plan to investigate the existence and decay characteristics of this isomer.

The nuclide ^{187}Pt is especially important in that it lies on the borderline between the near-spherical nuclei for A $\geqslant$ 187 and the strongly-deformed shapes of the far neutron-deficient region A $\leqslant$ 186. It is also important in that the odd-mass Pt isotopes possibly can be used to study the coupling of an odd neutron to a Pt core, in order to ascertain whether or not there are distinct proton contributions to the collective degrees of freedom, as is suggested by the interacting boson-fermion approximation (IBFA)[7].

---

[5] M. A. Grimm, Jr., PhD Thesis, Georgia Institute of Technology (1978)

[6] A. Ben Braham, et al., Nuclear Phys. A332, 397 (1979)

[7] F. Iachello, "How Well Can We Predict Nuclei Far from Stability?" in Future Directions in Studies of Nuclei far from Stability, edited by J.H. Hamilton, E. H. Spejewski, C. R. Bingham, and E. F. Zganjar (North-Holland Publishing Co., Amsterdam, 1980); p.281ff

---

It has been suggested that the proton (neutron) contributions can be probed by the coupling of the collective modes to an unpaired neutron (proton). The decay scheme ^{187m,g}Au $\rightarrow$ ^{187}Pt will form part of the PhD thesis of Mr. Bruce Gnade.

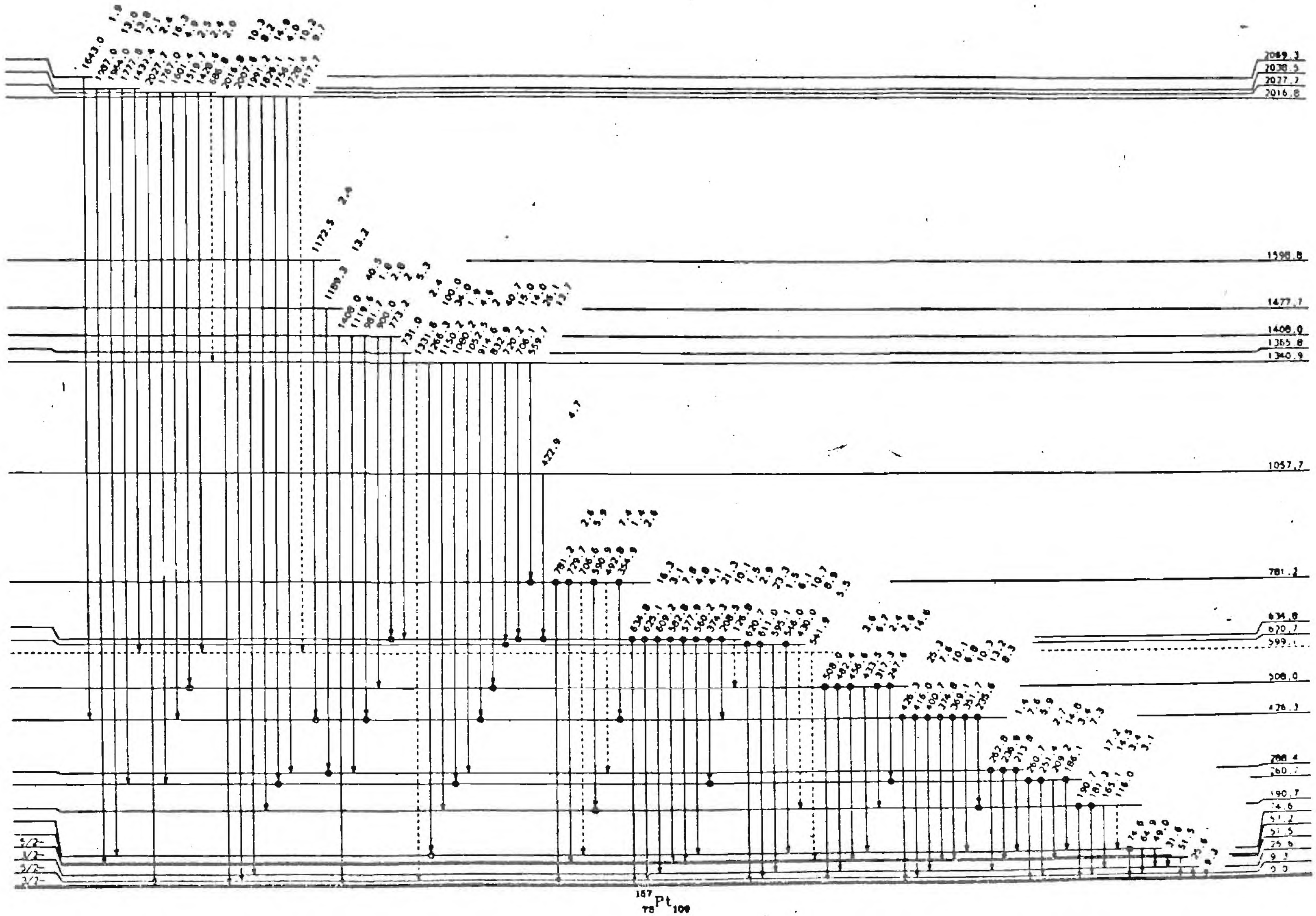


Figure 2 Decay Scheme for ^{187}Au. Coincidences are denoted by ● .

2.5 Lifetimes of the $g_{7/2}$ Intruder State Band Levels in ^{109}Ag from ^{109}Pd (13.43 h) Decay

The measurement of lifetimes of states in ^{109}Ag believed to be members of the $g_{7/2}$ intruder band has been performed with delayed coincidence techniques (300 picosec to 20 nanosec) at Georgia Tech. A system, consisting of a plastic scintillator and a Ge(Li) detector utilizing state-of-the-art amplitude and risetime-compensated (ARC) timing modules, was used to study lifetimes of levels populated in the decay of 13.43 h ^{109}Pd, sources of which were prepared in the Georgia Tech Research Reactor by the enriched ^{108}Pd(n,γ) reaction. The evaluation of the present data results in a value of approximately 0.8 nanosec for the lifetime of the 3/2+, 724.4 keV level, believed to be the second member of the intruder band, consistent with our previous determination of the approximate range of this lifetime.

Data of excellent statistical quality were obtained, and even though only 0.0018% of all decays populated the 1/2+, 707.0 keV band head member, no measureable lifetime of the 707.0 keV member was obtained. This observation is consistent with a possibility that a doublet exists near 707.0 keV, and that the member populated in the decay of ^{109}Pd is not the band head.

The latest data also indicate the presence of a γ-ray at 697 keV in coincidence with low-energy transitions. The tentative placement of this transition between the 697 keV level and the 1/2- ground-state in ^{109}Ag would conflict with the reported deexcitation of the 697 keV level to the 9/2+, 132 keV level and the 7/2+, 88 keV isomeric state [8)] (see Fig. 3).

[8] F. El-Bedewi, Z Miligy, and H. Hanafi, Acta Phys. (Hungary) 38, 153 (1975)

Additional measurements to resolve this apparent disagreement are in progress.

Fig. 3 - Partial decay scheme for ^{109}Ag showing the 1/2+ and 3/2+ states at 707 and 724.4 keV which are possible candidates for members of the $g_{9/2}$ intruder band. Also shown is the 697 keV level which on the basis of its decay to both high-spin states (7/2+ and 9/2+) and possibly to a low-spin state (1/2-) indicates a questionable assignment of this level.

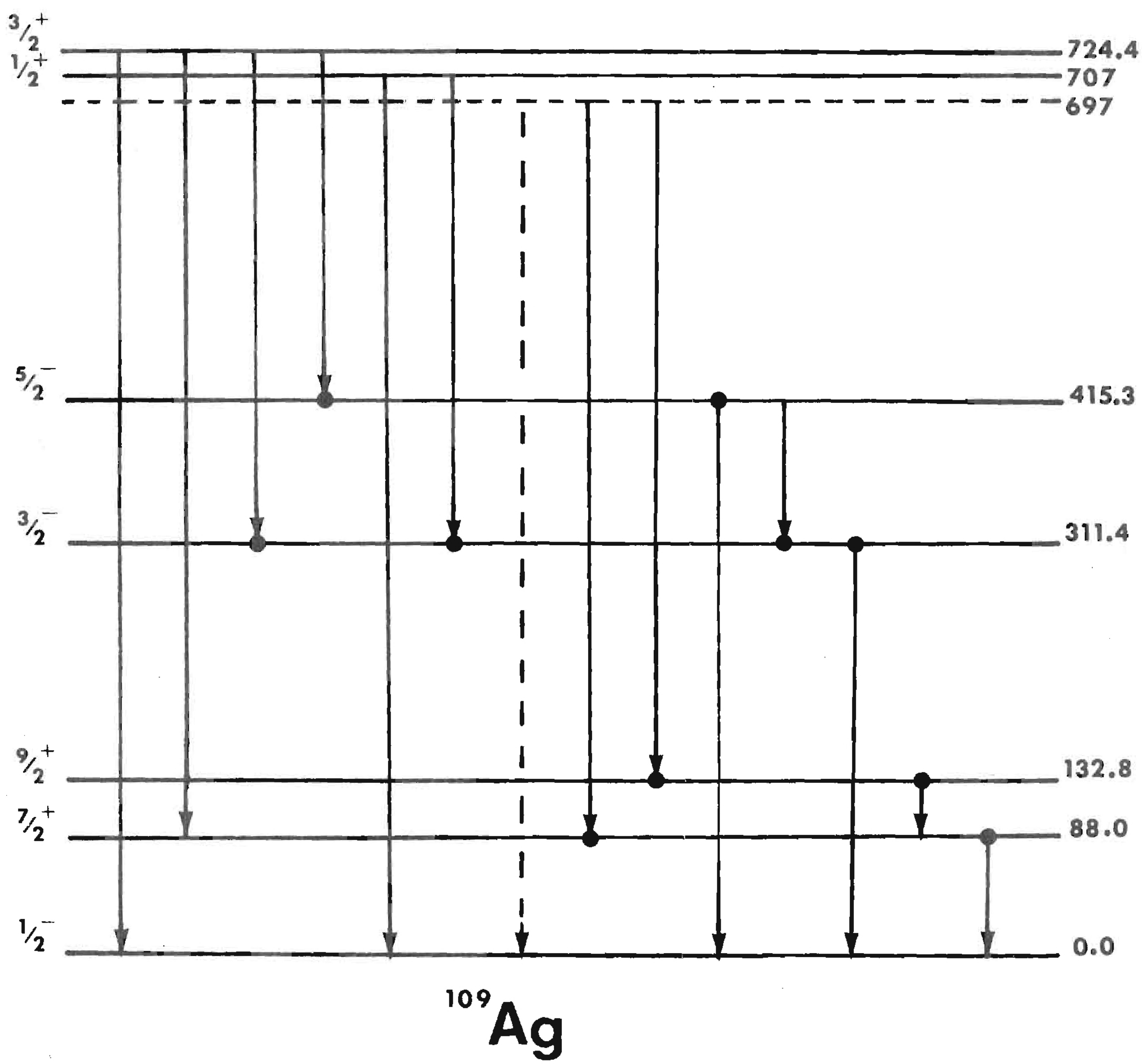


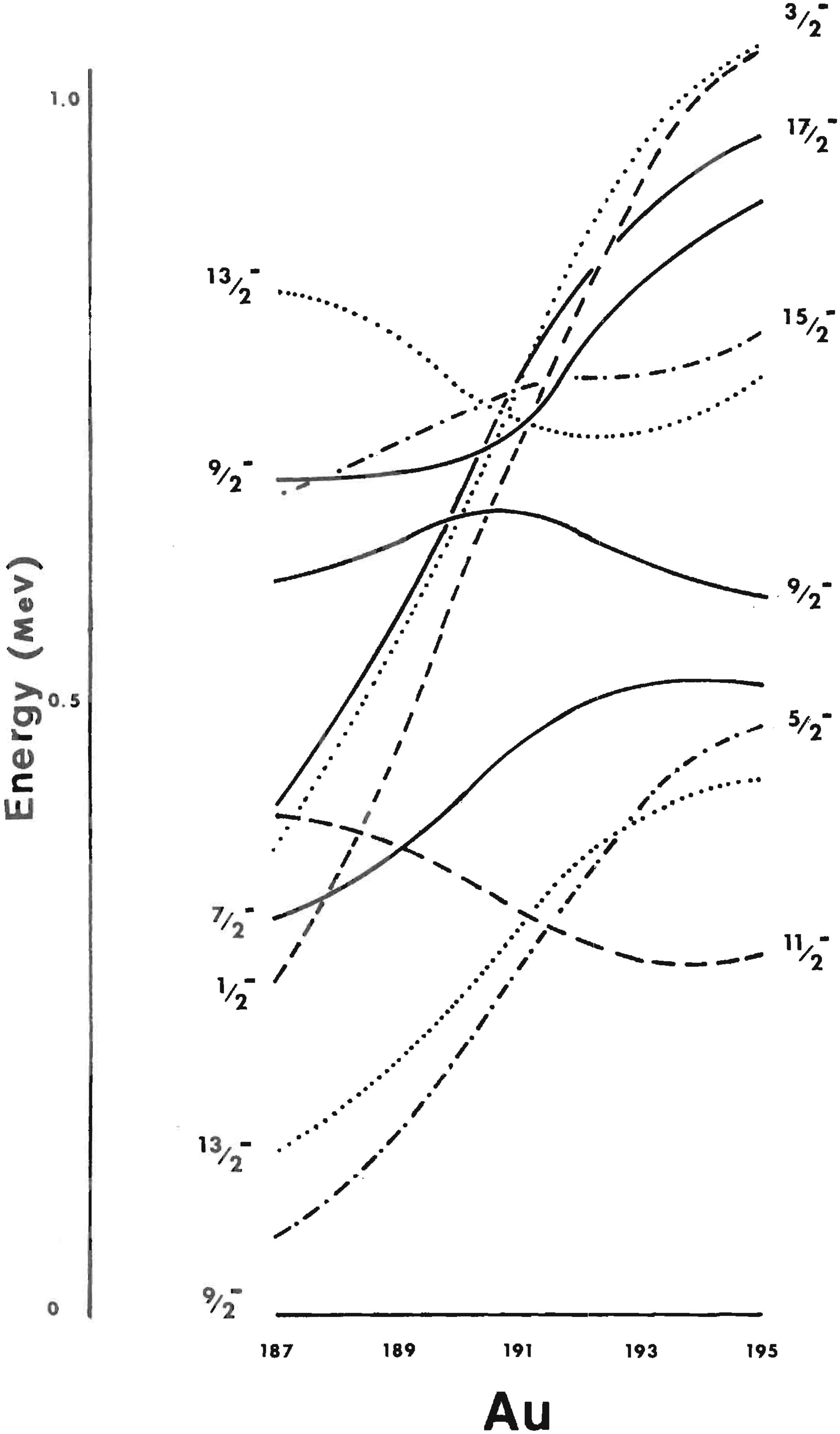
Fig. 3

3.0 Systematic Investigation of Interacting Boson-Fermion Approximation Predictions and Comparison with Odd-A Gold Isotopes

An extensive systematic comparison of the Interacting Boson-Fermion Approximation Model predictions with current experimental data on neutron-deficient gold isotopes was performed. To our knowledge, this is the only investigation of a systematic region using the IBFA model. The calculations were carried out with the computer codes "PHINT" and "ODDA" with initial parameters graciously supplied by F. Iachello and O. Scholten (of Yale University and K.V.I., Gröningen, The Netherlands, resp.) and in collaboration with an evaluation of the model by J. L. Wood (School of Physics, Georgia Tech).

In this comparison, our emphasis has been on the odd-A gold isotopes, and in particular, the coupling of the $h_{9/2}$ proton to the even Pt cores. The model predictions for this coupling for $^{187-195}$Au are shown in Fig. 4 for levels below 1.0 MeV, while Fig. 5 shows a comparison of the experimental data with the IBFA calculations for ^{189}Au. The agreement between experiment and theory is quite impressive, considering that in this prescription the parameters used are applied within a given shell and are not the result of a fitting to experimental data. (R. A. Braga)

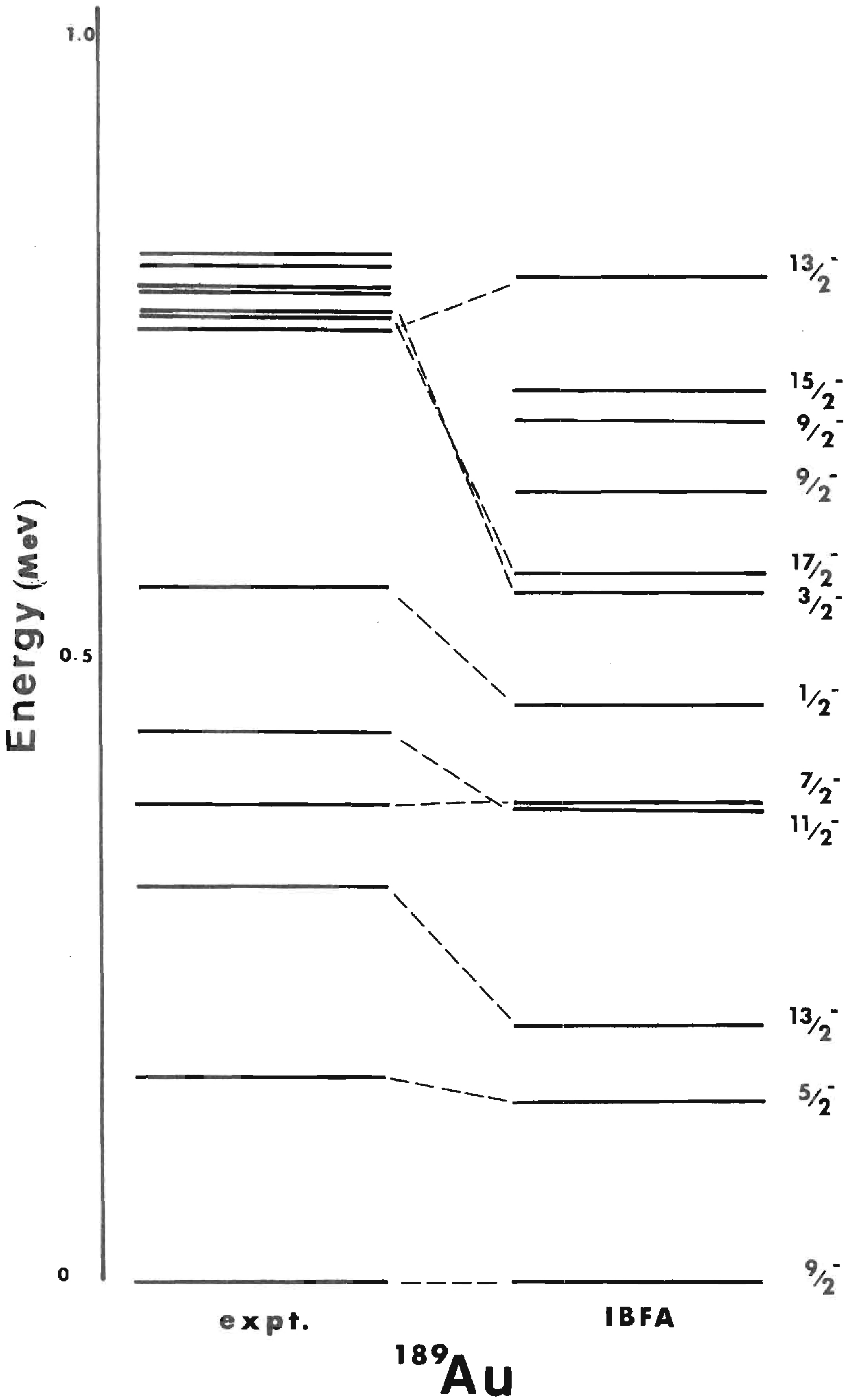
Fig. 4 - Calculated energy spectra for the coupling of the $h_{9/2}$ proton to the even Pt cores for $^{189-193}Au$. As the neutron number decreases and boson number increases, there is a transition away from the O(6) (γ-soft rotor) limit toward the SU(3) limit (axial rotor).



3/2⁻
17/2⁻
13/2⁻
15/2⁻
9/2⁻
9/2⁻
5/2⁻
7/2⁻
1/2⁻
11/2⁻
13/2⁻
9/2⁻
1.0
0.5
0
Energy (MeV)
187
189
191
193
195
Au

Fig. 4

Fig. 5 - Comparison of the IBFA calculated energy spectra with experimental energy levels for ^{189}Au for levels below 1.0 MeV. Agreement is very good considering that the only adjustable parameter is the number of bosons ($n_T = n_\pi + n_\nu = 10$; $n_\pi = 2$, $n_\nu = 8$).



1.0
0.5
0
Energy (MeV)
13/2-
15/2-
9/2-
9/2-
17/2-
3/2-
1/2-
7/2-
11/2-
13/2-
5/2-
9/2-
expt.
IBFA
189Au

Fig. 5

4.0 International Intercomparison of ^{133}Ba Gamma-ray Standards

The participation of our group in the international comparison of γ-ray emission-rate measurements on ^{133}Ba (10.74 y) sources, organized by the Working Group on Alpha-, Beta-, Gamma-ray Spectroscopy of the International Committee for Radionuclide Metrology (ICRM), under the chairmanship of J. Legrand (France), and administered in the USA through the National Bureau of Standards, has been completed and a preliminary report circulated among the participants. A summary of our measured emission rates is given in Table III.

Our participation in this investigation is the result of our ongoing interest in characterizing the efficiency response of large-volume Ge detectors (such as those used at UNISOR) for the energy region below 200 keV. In this region, the efficiency response exhibits a rapid curvature, and the ability to obtain accurate intensities for the γ-rays observed in our decay scheme studies have previously been hindered by the lack of emission-rate standards in this energy region.

Table III - Emission Rates of Gamma-rays from ^{133}Ba (10.74 y)
Present work

Energy (keV)		Emission rate per 100 decays
30.625 30.973	$K_{\alpha_{2,1}}$	99.87
35.4	K_{β}	23.22
53.155		2.181
79.621		2.848
80.997		35.50
160.6		0.6559
223.2		0.4584
276.4		7.006
302.9		18.02
356.0		61.10
383.8		8.746

5.0 X-rays and Inner Shell Ionization Phenomena from Radioactive Sources

5.1 Studies of the L_1 Subshell

Measurement of L_1 subshell x-ray fluorescence and Coster-Kronig yields has been difficult for two important reasons: (1) at high Z, most of the L_1 atomic vacancy states decay by Coster-Kronig transitions that transfer vacancies to the L_2 and L_3 subshells, thus making it difficult to observe L_1 characteristic x rays separately; and (2) unlike L_2 and L_3 vacancy states, which are final states from the $K_{\alpha 2}$ and K_{α_1} radiative transitions, respectively, the L_1 vacancies are not final states in the radiative decay of K vacancy states, thus precluding the use of x ray and x-ray coincidence techniques. However, nuclear transitions, in which L_1 vacancy production has a high probability, have been used in the past as convenient sources for study of L_1 atomic vacancy states. With the presently available high resolution x-ray detectors and state-of-the-art timing coincidence techniques, these measurements can be extended to a wide range of elements, using nuclear transitions to generate the L_1 vacancies.

The present measurements of the L subshell yields for Z = 82 are made using the long-lived (33.4 y) ^{207}Bi sources which decay by electron capture to ^{207}Pb. An XX·t three-parameter arrangement with the ND-4420 multiparameter analyzer is used to collect the coincidence spectra as two of the parameters, as well as the TAC spectrum as the third parameter. A fourth ADC unit is also used to collect the necessary singles spectra. The true coincidence events fall into a broad peak (60 to 100 nsec) in the TAC spectrum and stand over a very small continuous distribution of events that are primarily due to chance coincidences. An analysis of the profile of the TAC spectrum was first carried out to make sure that all of the true coincidences in any required spectrum are completely included. This completeness is critical to an accurate determination of all L subshell quantities.

The L_1 subshell yields are obtained from the analysis of the L x rays in coincidence with the L conversion electrons resulting from the 1063 keV transitions which produce predominantly L_1 vacancies. Two alternative procedures were used in analyzing the coincidence spectrum. In the first, the coincidence rates of $L_{\alpha+\ell}$, $L_{\beta+\eta}$, and L_γ x rays were evaluated separately, and using the relations given by Rao, et al.[9)], the values of

---

[9] P. V. Rao, R.E. Wood, J. M. Palms and R. W. Fink, Phys. Rev. 178, 1997 (1969)

ω_1, f_{12}, and f_{13} are deduced. In the second procedure, the spectrum of coincident L_γ x rays was analyzed into its two components characteristic of L_2 and L_1 subshells, and ω_1 was obtained directly from the number of L_1 characteristic x ray present. The second procedure also leads to a direct determination of the radiative branching ratio s_1 for the L_1 subshell.

The L_1 subshell yields at Z = 56 will be determined using the radioactive source ^{137}Cs (29.9 y) which decays to ^{137}Ba. The L x rays in coincidence with 656 keV L-conversion electrons will be analyzed using the techniques employed in the case of ^{207}Bi. (M. Tan, P. V. Rao, R. A. Barga and R. W. Fink)

5.2 Studies of the L_2 and L_3 Subshells

The L_2 and L_3 subshell yields were obtained from the L x-ray — K_{α_2} x ray and L x-ray — K_{α_1} coincidence rates, respectively. In particular, the measurement of f_{23}, the Coster-Kronig transition probability of $L_2 \rightarrow L_3$ vacancy transfers, was obtained in two alternative procedures. The first made use of the observed ratio of L_3 characteristic x rays and L_2 characteristic x rays present in the spectrum of L x rays in coincidence with a K_{α_2} x-ray gate. The second procedure was based upon observing the ratio of K_{α_2} and K_{α_1} x rays in coincidence with an L_α x-ray gate. The analysis of the coincidence spectrum was based upon the improved method for tailing corrections given by Gnade, et al.[10).]

---

[10]B.E. Gnade, R. A. Braga, W. R. Western, J. L. Wood and R. W. Fink, Nucl. Instr. Meth. 164, 163 (1979)

A completely new set of measurements of f_{23} is being undertaken using the improved techniques available for the analysis of coincidence spectra. These measurements, as a function of atomic number Z, are very important and necessary to compare with the theoretical estimates based on the recent relativistic calculations[11)] of the radiationless transitions of L-subshell vacancy states. The next measurement will be that of ^{170}Tm (130 d) to ^{170}Yb to measure f_{23} at Z = 70.

---

[11]M.H. Chen, E. Laiman, M. Aoyagi and Hans Mark, Phys. Rev. A19, 2053 (1979)

The new results at Z = 82 from ^{207}Bi decay will be published in the near future. (M. Tan, P.V. Rao, R.A. Braga and R. W. Fink)

5.3 The Decay Energy of ^{207}Bi (33.4 y)

The only available estimate of the total decay energy in the electron capture decay of ^{207}Bi to ^{207}Pb is based upon a very early measurement of the L x-ray - 1770 keV γ-ray coincidence rate (which determined the L-capture fraction P_L = 0.663 from which Q_{EC} = 62.4 keV to the 2339 keV level in ^{207}Pb) obtained using proportional and NaI(Tl) counters[12)]. It was assumed from the

---

[12]De Beer, Blok, and Blok, Physica 30, 1938 (1964)

---

experimental data existing at that time that there is no K capture to the 2339 keV level. This evidence remains to be verified and substantiated. The currently accepted ^{207}Bi-^{207}Pb mass difference (2400.4 keV) rests on the validity of this assumption and on this single early measurement of the L capture probability. In view of the fact that the nuclide ^{207}Bi is an important calibration standard and the necessity to use an accurate value of the decay energy in estimating the K and L electron capture probabilities and other inner shell ionization rates, a measurement of the rates of K and L x rays in coincidence with 1770 keV γ-rays is in progress, utilizing a large volume high resolution Ge(Li) γ-ray detector and high resolution Ge(HP) x-ray detector, together with three-parameter Xγ·t analysis. This work will provide a precise value of the decay energy Q_{EC} and the individual L-subshell orbital electron capture probabilities for comparison with theory. (M. Tan, P. V. Rao, R. A. Braga and R. W. Fink)

6.0 Miscellaneous Topics

6.1 Preparation of Reactor-Produced, Carrier-Free ^{18}F as the Potassium 18-Crown-6 Complex for Synthesis of Labelled Organic Compounds

An anion exchange and distillation procedure has been developed for preparing reactor-produced carrier-free ^{18}F as $K^{18}F$ complexed with 18-crown 6 in acetonitrile for subsequent syntheses of labelled organic compounds. The reaction sequence $^{6}Li(n,t)^{4}He$-$^{16}O(t,n)$ ^{18}F produced yields of approximately 250 milliCuries of ^{18}F per hour per gram of 96% enriched ^{6}Li as $^{6}LiOH{\cdot}H_2O$ target in a reactor thermal neutron flux of 3×10^{13} n/cm^2·sec. Yields of tritium-free carrier-free ^{18}F dissolved in the crown ether solution typically reach 85 ± 5% within 20-30 minutes required for the radiochemical procedure. A full manuscript has been accepted for publication in the International Journal of Applied Radiation & Isotopes by B. E. Gnade, G. P. Schwaiger, C. L. Liotta, and R. W. Fink

6.2 CDC-Cyber-70/74 Computer Codes

The computer code "NPBOS" (written by O. Scholten, K.V.I., Gröningen, The Netherlands) has been adapted for operation on the Georgia Tech CDC Cyber 70/74 computer. This code calculates energies and eigenvalues for positive and negative parity states for even-A nuclei in the framework of the interacting boson-fermion approximation model. This calculation differs from that of the code "PHINT" in that a distinction is made between proton and neutron bosons.

During the past year, we have made a major effort to reduce the core requirements of our data handling codes; an effort made necessary because of the decreased computer availability resulting from the increased demands upon on the Georgia Tech Cyber system. Since the majority of our computer usage is in data processing (ie, sorting of coincidence spectra, peak-shape analysis, etc.) as opposed to numerical calculations, our jobs require extensive mass storage, as well as peripheral devices, although for short periods of time (1 - 2 min). Our core-efficient data handling codes now provide satisfactory data processing without extremely long "turn-around" times. (R.A. Braga)

6.3 Equipment added during 1980

During this year, we added a Nuclear Data Model ND-570 Analog-to-Digital converter (ADC) to our ND-4420 multiparameter multichannel analyzer. This 80 MHz ADC now gives us four compatible ADC's providing the ability to perform more sophisticated multiparameter multiconfigurational experiments.

In addition, we are replacing old (> 10 years) NIM logic modules with new state-of-the-art models. A logic shaper and delay (Canberra Model 2055) and a constant-fraction timing single-channel analyzer (Canberra Model 2035A) have been ordered. The modules will provide better timing characteristics, noise reduction, and count-rate stability for logic signal processing in our timing circuits.

Our Chemistry Machine Shop fabricated beam-line flanges and a port viewing window for on-line operation of the laser spectroscopy facility at UNISOR.

7.0 Personnel

Senior Staff

Dr. R. W. Fink, Professor of Chemistry
Principal Investigator (1/4 time, 12 months)

Dr. R. A. Braga, Research Associate
(65% DOE + 35% teaching in School of Chemistry, 12 months;
full-time DOE from September, 1980)

Dr. Mustafa Tan, Asst. Prof. Physics on leave from Atatürk Univ., Turkey
Research Associate (1/2 time DOE, 9 months from May, 1980)

Dr. P. Venugopala Rao, Assoc. Prof. Physics, Emory University
Research Associate (1/2 time DOE, 2 months, summer, 1980)

Graduate Students

Mr. Bruce E. Gnade (Chemistry). Continuing PhD thesis research utilizing UNISOR facilities (1/2 time Research Assistant, DOE, 12 months)

Mr. Paul Semmes (Chemistry) [B.S. Chem, June, 1980. Georgia Tech]
Beginning PhD thesis research utilizing UNISOR facilities
(1/2 time Research Assistant, DOE, from September, 1980;
1/2 time Teaching Assistant, June - August, 1980;
Special problem student in nuclear chemistry 1979 - June, 1980)

Mr. Gary P. Schwaiger (Nuclear Engineering). Completing M.S. in N.E. Special problem student in nuclear chemistry since August 1979. Plans to join nuclear chemistry upon completion of M.S. degree and to do PhD research utilizing UNISOR facilities. No DOE support

Mr. Chris Papanicolopulos (Physics) Terminated March, 1980

Mr. W. S. Lewis (Chemistry) Terminated April, 1980

Special Problem Students

Mr. William Pekny (Chemistry). Senior Special Problem Student in nuclear chemistry, finishing June, 1980. No DOE support. Worked on A = 201 UNISOR data analysis.

Mr. Steve Sewell, Summer program high school student 1980. No DOE support. Worked on UNISOR data analysis.

Miss Lisa Coffman, Summer program high school student 1980. No DOE support Worked on UNISOR data analysis.

8.0 List of Publications and Presentations at Meetings

1) "Very Slow M4 Transitions and Shell-Model Intruder States in ^{199,201}Bi," R. A. Braga, W. R. Western, J. L. Wood, R. W. Fink, R. Stone, C. R. Bingham, and L. L. Riedinger, Nuclear Phys. A (in press, 1980) and Bull. Am. Phys. Soc. 24, 836 (1979) Knoxville, Tenn., October, 1979). [ORO-3346-238]

2) "Decays of ^{117}Xe → ^{117}I → ^{117}Te," R. S. Lee...W. D. Schmidt-Ott, A. C. Xenoulis, R. W. Fink, and other UNISOR coauthors, Phys. Rev. C (submitted, 1980) [ORO-3346-239]

3) "The Use of Systematics in the Interpretation of Nuclear Structure far from the Beta Stable Region," J. L. Wood (invited paper) in Future Directions in Studies of Nuclei far from Stability, edited by J. H. Hamilton, et al. (North-Holland Publishing Co., Amsterdam, 1980); pp. 37-48

4) "Excited States in ^{189,190}Pt from Decays of $^{189m,\ 190g}$Au," B. E. Gnade, J. L. Wood, and R. W. Fink, Bull Am. Phys. Soc. 25 (1980)[ORO-3346-241]

5) "Studies of Z = 81 Transitional Nuclei I. ^{197}Pb Decay," L. L. Collins, L.L. Riedinger, G. D. O'Kelley, C. R. Bingham, M. S. Rapaport, J. L. Wood, and R. W. Fink, Phys. Rev. C (submitted, 1979)[ORO-3346-221

6) "Studies of Z = 81 Transitional Nuclei II. ^{193}Pb and ^{195}Pb Decays," L. L. Collins, L.L. Riedinger, A. C. Kahler, C. R. Bingham, G. D. O'Kelley, J. L. Wood, R. W. Fink, A. G. Schmidt, E. H. Spejewski, H. K. Carter, R. L. Mlekodaj, E. F. Zganjar, and J.H. Hamilton, to be submitted, 1980 [ORO-3346-222]

7) "The $h_{9/2}$ Bands in $^{185-195}$Au and the Interacting Boson-Fermion Approximation," R. A. Braga and J. L. Wood, Bull. Am. Phys. Soc. 25 (in press, 1980) (Minneapolis, Minn, October, 1980) [ORO-3346-240]

8) "An Inexpensive Pulser for the Adjustment of Subnanosec Walk in Timing Circuits," R. A. Braga, G. E. O'Brien, and R. W. Fink, Nucl. Instr. Meth. 163, 527 - 529 (1979)

9) "An Improved Measurement of the L_{2-3}-Subshell X-ray Fluorescence and Coster-Kronig Yields at Z = 64 and 67," B. E. Gnade, R. A. Braga, and R. W. Fink, Phys. Rev. C21, 2025 - 2032 (1980) and Bull Am. Phys. Soc. 24, 835 (1979) Knoxville, Tenn, October, 1979) [ORO-3346-233]

10) "Preparation of Reactor-Produced, Carrier-Free ^{18}F-Fluoride as the Potassium 18-Crown-6 Complex for Synthesis of Labelled Organic Compounds," B. E. Gnade, G. P. Schwaiger, C. L. Liotta, and R. W. Fink, Int. J. Appl. Radiat. Isotopes (accepted and in press, June, 1980)

11) BOOK CHAPTER: "Analysis of Zn and Cu," R. W. Fink and J. Carden, Chapt. 2,3, in Zinc and Copper in Medicine, edited by R. M. Sarper and Z. A. Karcioglu (C.C. Thomas Publishers, Springfield, Ohio, 1980); pp.

12) BOOK CHAPTER: "Properties of Si and Ge Semiconductor Detectors for X-ray Spectrometry," R. W. Fink (invited paper), Proc. Symp. on Energy-Dispersive X-ray Spectrometry (National Bureau of Standards, 1980) pp [ORO-3346-231]

13) BOOK CHAPTER: "Tables of Experimental Values of X-ray Fluorescence and Coster-Kronig Yields for the K-, L-, and M-Shells," R. W. Fink and P. V. Rao, in Handbook of Spectroscopy, Vol. 3 (CRC Publishing Co., Boca Raton, Florida, 1980); pp.

14) BOOK CHAPTER: "Thermal Neutron Cross Sections and Resonance Integrals for Activation Analysis," R. W. Fink, in Handbook of Spectroscopy, Vol. 3 (CRC Publishing Company, Boca Raton, Florida, 1980); pp.
[ORO-3346-206(rev.)]

15) R. W. Fink (invited member of the panel), Workshop on Instrumentation and Analysis for Nuclear Fuel Reprocessing Hot Pilot Plant, May 5 - 7, 1980, Oak Ridge National Laboratory, cosponsored by the Subcommittee on Nuclear and Radiochemistry of the Committee on Chemical Sciences of the National Research Council

-78a

PUBLICATION BY AEC AUTHORIZED ☐

NOTICE OF RESEARCH PROJECT
SCIENCE INFORMATION EXCHANGE
SMITHSONIAN INSTITUTION

SIE NO.

DOE CONTRACT NO. DE-AS05-76ER0-3346

SUPPORTING DIV. OR OFFICE: U.S. Department of Energy
Energy Research and Development Administration

NAME & ADDRESS OF CONTRACTOR OR INSTITUTION: (State the division, department, or professional school, medical, graduate or other, with which this project should be identified.)

School of Chemistry
Georgia Institute of Technology
Atlanta, Georgia 30332

TITLE OF PROJECT:

Nuclear Chemistry Research and Spectroscopy with Radioactive Sources

NAMES, DEPARTMENT, AND OFFICIAL TITLES OF PRINCIPAL INVESTIGATORS AND OTHER PROFESSIONAL SCIENTIFIC PERSONNEL: (not including graduate students) engaged on the project, and fraction of man-year devoted to the project by each person.

Dr. Richard W. Fink, Professor of Chemistry, Principal Investigator (1/2 time)
Dr. Robert A. Braga, Research Associate (full-time)
Dr. Mustafa Tan, Research Associate (1/2 time)
Dr. P. Venugopala Rao, Senior Research Associate (1/2 time summers only)

NO. OF GRADUATE STUDENTS ON PROJECT: 3 NO. OF GRADUATE STUDENT MAN-YEARS: 2

SUMMARY OF PROPOSED WORK: (200-300 words, omit Confidential Data). Summaries are exchanged with government and private agencies supporting research, are supplied to investigaters upon request, and may be published in AEC documents. Make summaries substantive, giving initially and for each annual revision the following: OBJECTIVE; SCIENTIFIC BACKGROUND FOR STUDY; PROPOSED PROCEDURE; TEST OBJECTS AND AGENTS.

Radioactivity is the phenomenon which underlies all of the current work in nuclear chemistry research and spectroscopy at Georgia Tech. Our principal effort remains centered on far-unstable nuclei produced by heavy ion beams from the Holifield Heavy Ion Research Facility (HHIRF) and studied on-line with the University Isotope Separator at Oak Ridge (UNISOR). The regions on both sides of the Z = 82 closed shell and around Z = 56 contain the nuclei of current experimental interest. The use of radioactive decay to excite the low-spin, low-energy states in the daughter nuclei is the only means of exploring the low-spin level structures in far-from-stable nuclei. We continue to explore the applicability of such particle-core coupling theories as the Interacting Boson-Fermion Approximation (IBFA) model. On campus x-ray coincidence studies and nuclear lifetime measurements augment our UNISOR-related research.

RESULTS TO DATE:

See Annual Progress Report, ORO-3346-242 (October 31, 1980) for the 16th year of this program.

10 publications by the Nuclear Chemistry group during 1979/80 plus 4 book chapters during this period in press by Prof. R. W. Fink.

BUDGET	PROGRAM CATEGORY NO.
PRIMARY	
SECONDARY	

Signature of Principal Investigator

DATE: SEP 24 1980

INVESTIGATOR — DO NOT USE THIS SPACE

G-33-645

GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

OFFICE OF
THE
COMPTROLLER

January 14, 1981

Mr. A. H. Frost, Jr., Chief
Research Contracts, Procedures
and Reports Branch
Contract Division
U.S. Department of Energy
P.O. Box E
Oak Ridge, Tennessee 37830

Dear Mr. Frost:

Enclosed in triplicate is the Statement of Costs for Contract Number DE-AS05-76ER0334, M015 covering the period February 1, 1979 through January 31, 1980.

If you have any questions or desire additional information, please let us know.

Sincerely,

David V. Welch, Manager
Grants and Contracts Accounting

DVW/GS/jb
Enclosures
cc: Dr. J. A. Bertrand
Dr. R. W. Fink
Mr. J. W. Dees
Mr. O. H. Rodgers
File G-33-645

DISTRIBUTED ON 1/28/81

Rec'd 1

GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA, GEORGIA
U.S. Department of Energy
Statement of Costs

1. Name and Address of Contractor: Georgia Institute of Technology
Atlanta, Georgia 30332

2. Contract Number: DE-AS05-76ER03346, Mod 15

3. Beginning and ending date of pertinent contract period: February 1, 1979 through January 31, 1980.

4. Costs incurred during the pertinent contract period:

a. Salaries and wages	$ 60,497.29
b. Equipment (see attached list) (A)	12,385.60
c. Travel (all domestic)	2,898.40
d. Other direct costs	16,402.79
e. Total direct expenditures	$ 92,184.08
f. Indirect charges	45,977.91

5. Total costs for items under Article A-II(a) for the pertinent contract period	$ 138,161.99
6. Support cost (See attachment) (B)	93,234.99
7. Cumulative support cost	$ 627,061.60
8. Accumulated support ceiling	629,930.00
9. The difference between lines 7 and 8	$ 2,868.40

I hereby certify that this report is true and correct to the best of my knowledge and belief and that the costs listed herein were incurred in connection with the performance of the research provided for under this contract and in accordance with the terms and conditions set forth therein.

R.W. Fink, Professor of Chemistry and Senior Investigator
Name and Title of Principal Investigator

Signature

DEC 30 1980
Date

David V. Welch, Manager, Grants and Contracts Accounting
Name and Title of Business Officer

Signature

1/14/81
Date

ATTACHMENT

EQUIPMENT

(A)

QUANTITY	DESCRIPTION	AMOUNT
1	ND4420 multichannel dual parameter analysis system	$ 10,757.60
1	ND NIM electronic module (ND-570 ADC) analog - to digital converter	1,628.00
		$ 12,385.60

(B)

6. Support Costs for the pertinent contract period, using percentage of 69% as stated in Article AIII, the amount chargeable to DOE would be $95,331.77 (69% of $138,161.99). However, only $93,234.99 has been charged to the DOE account. We prefer that the difference of $2,096.78 be treated as unexpended and available for expenditure during the subsequent contract period.